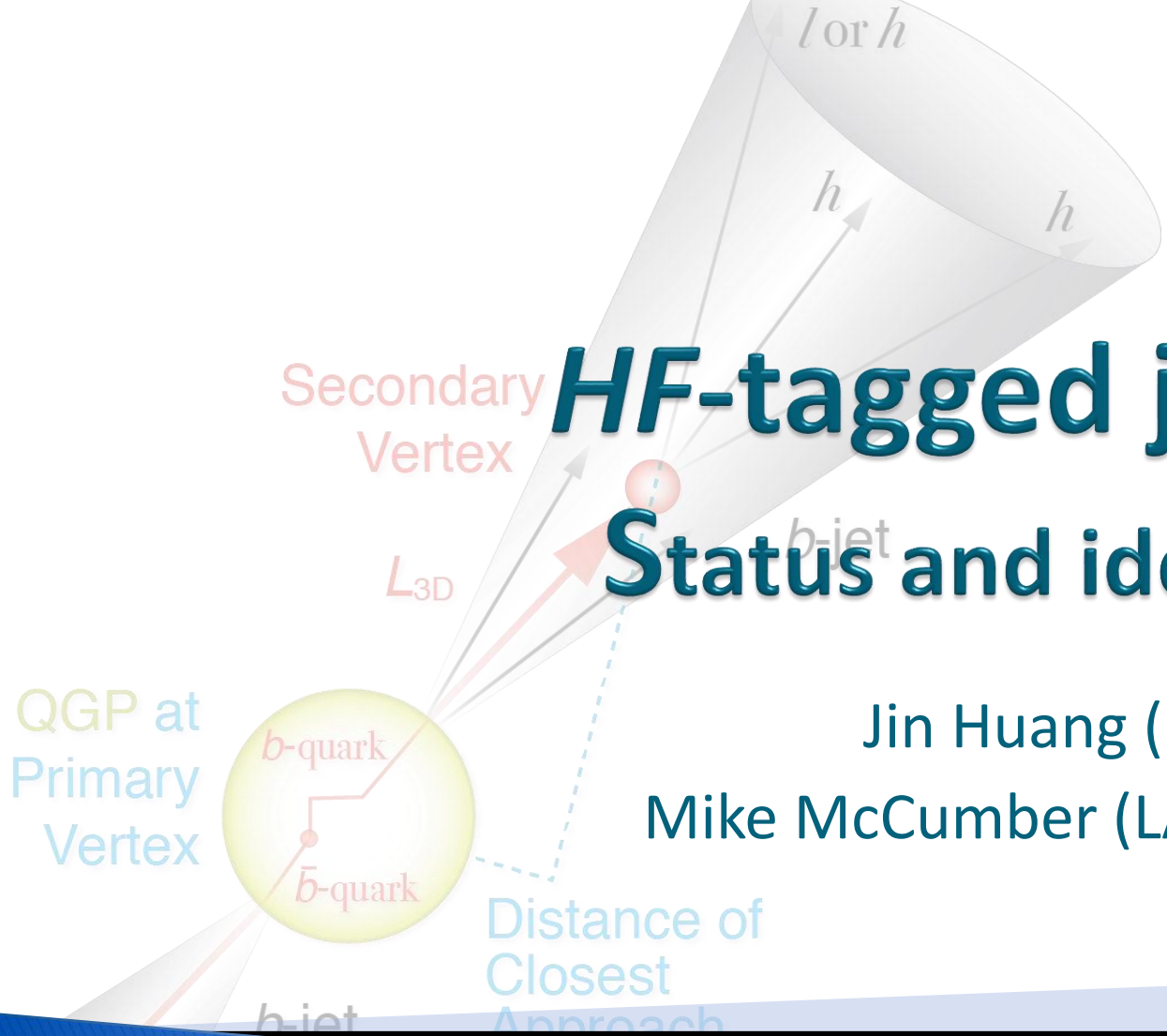


HF-tagged jet

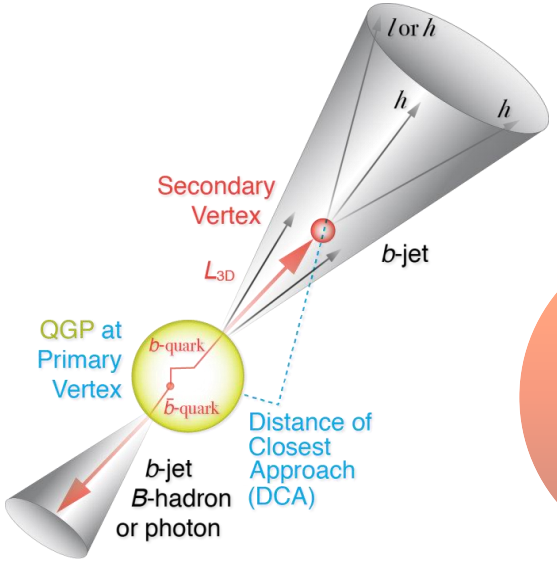
Status and ideas

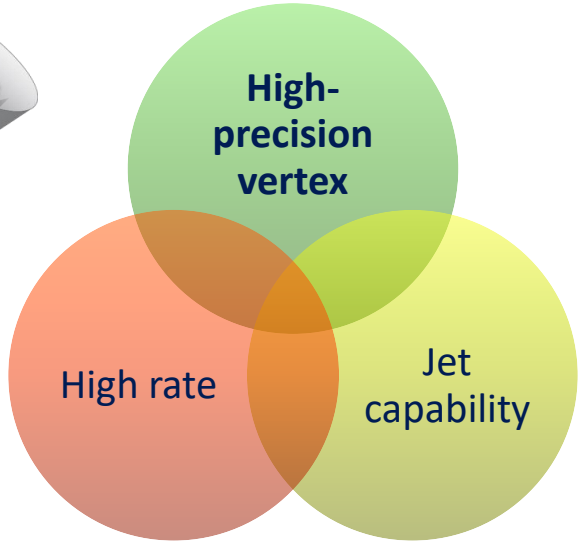
Jin Huang (BNL)

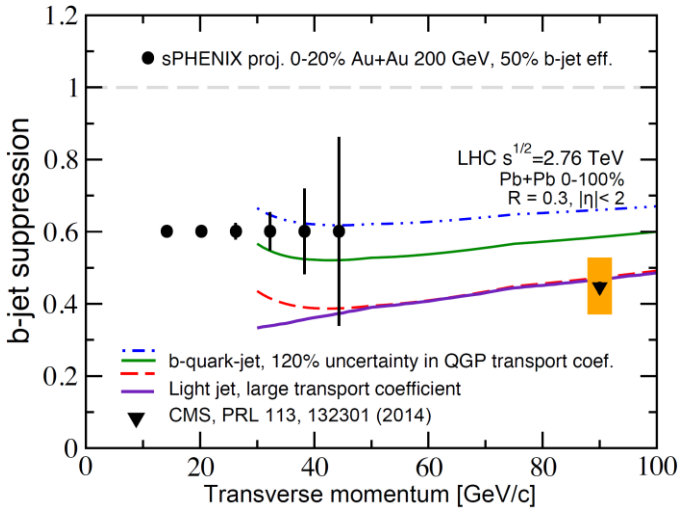
Mike McCumber (LANL)

PHENIX

Introduction







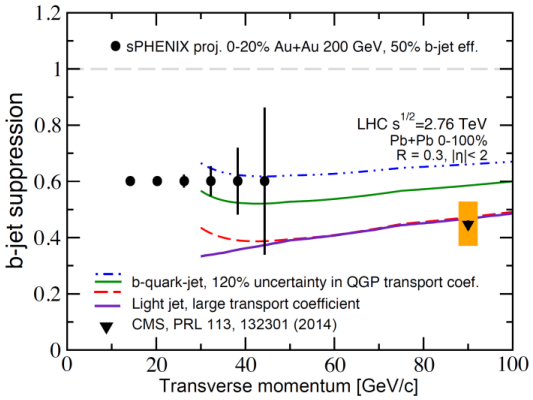
- HF-jet: in particular *b*-jet, when compared with much more abundant light-parton jet, provide differentiating sensitivity to collision VS radiative energy loss
- Detection technique employed: Jet + jet structure information enhancing *B*-hadron fraction, i.e: displaced track, high mass secondary vertex and enhanced leptonic decay products
- HF-jet topical group formed in Apr 2016 and initiated Geant4 based b-jet study in sPHENIX. Many progresses in simulation tool, b-jet tagger and studying new observables.
- In the new era of MVTX program, aim to expand the program in HF-meson program (See Xin's talk) and serve the detector consortium of MVTX (See Ming's talk)

Topical group organization

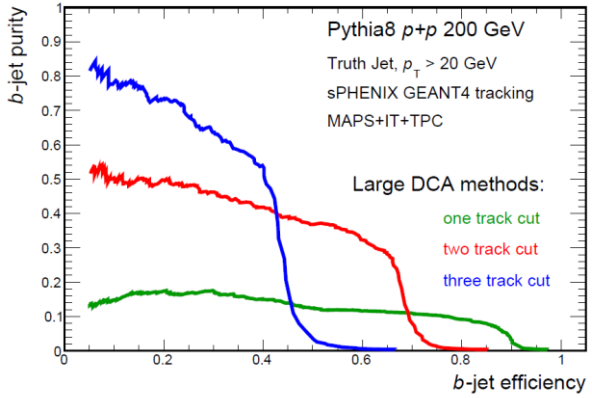
- Co-conveners
  - Jin Huang (Brookhaven National Lab) <jhuang@bnl.gov>
  - Mike McCumber (Los Alamos National Lab) <mccumber@bnl.gov>

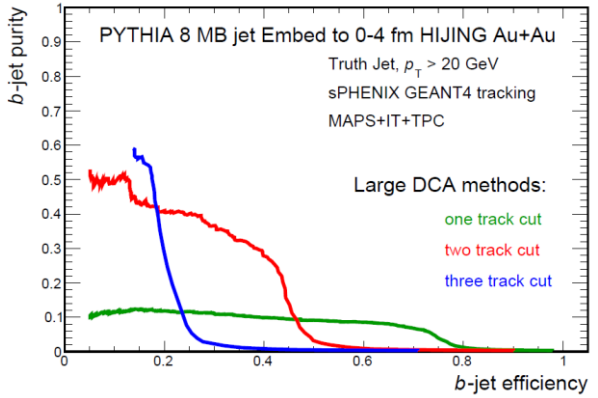
- We are very fortune to have a diligent team working on a wide spectrum of high-priority development
  - More manpower are always welcomed and needed!
- Communication:
  - Discussion email list: https://lists.bnl.gov/mailman/listinfo/sphenix-hf-jets-l
  - Wiki page under construction: https://wiki.bnl.gov/sPHENIX/index.php/Heavy_Flavor_Topical_Group
- Meetings/Events
  - Use weekly simulation meetings for updates, as many high-priority tasks involve software developments with tracking detector designs https://indico.bnl.gov/categoryDisplay.py?categId=88
  - Goal oriented irregular events:
    - New event: this meeting today
    - MAPS+HF-jet joint workfests, e.g. Jan 5-7 2017 @ Santa Fe
    - Pre-collaboration meeting work-fest on May 16-17, 2016
    - Initial TG meeting on Apr 22 , 2016

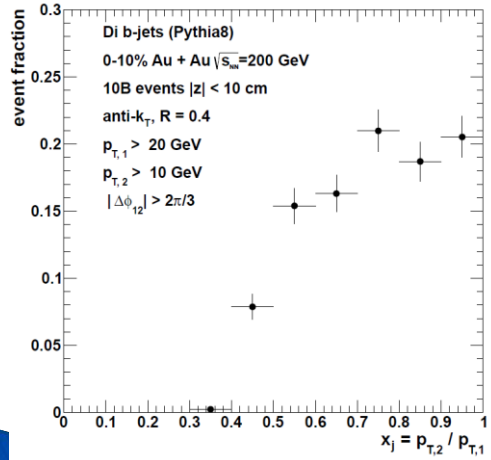
Delivered plots for MAPS pre-proposal

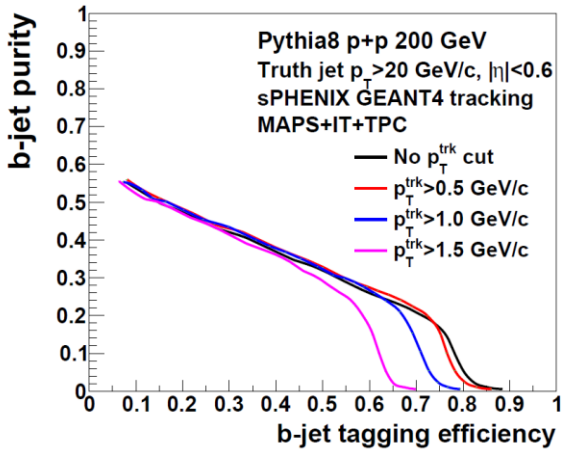


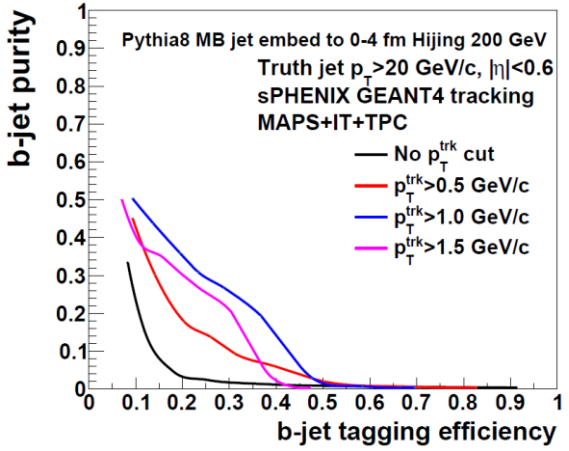
Curve update request, not yet received











Observable Projections

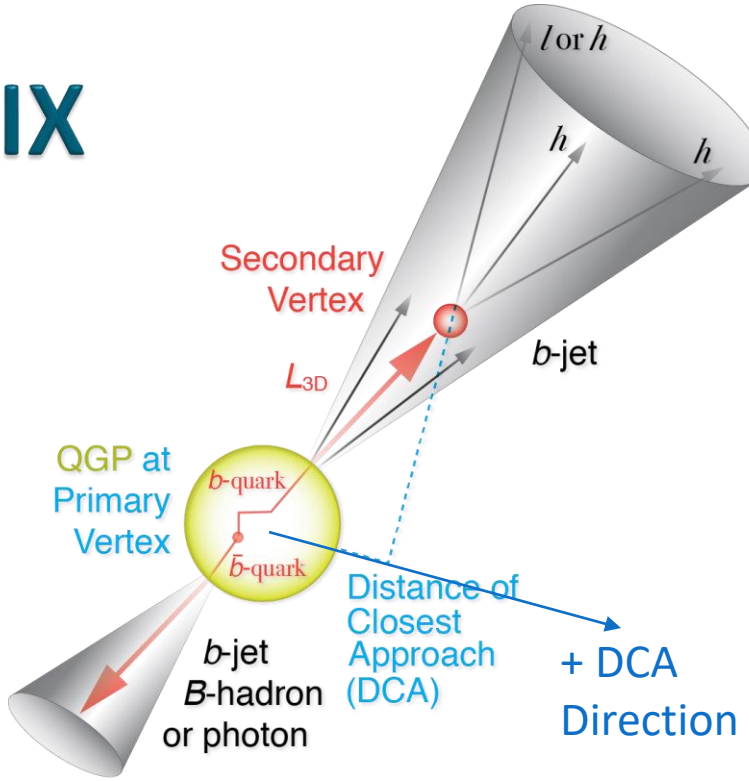
B-jet tagging in p+p

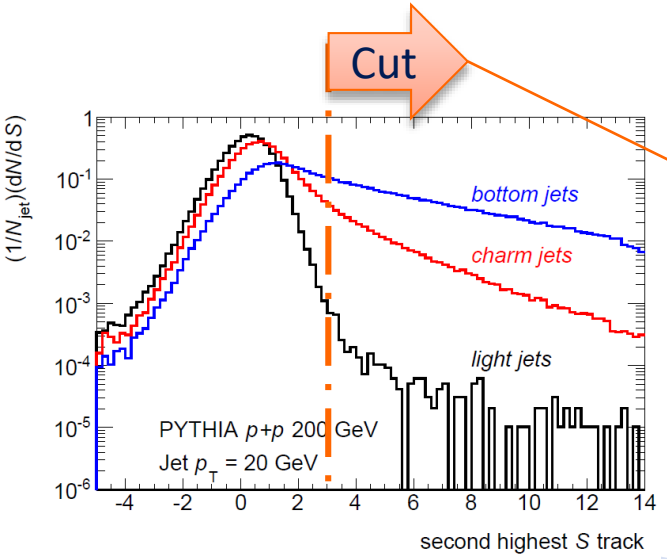
B-jet tagging in 10%C Au+Au

Tagging *b*-jets in sPHENIX

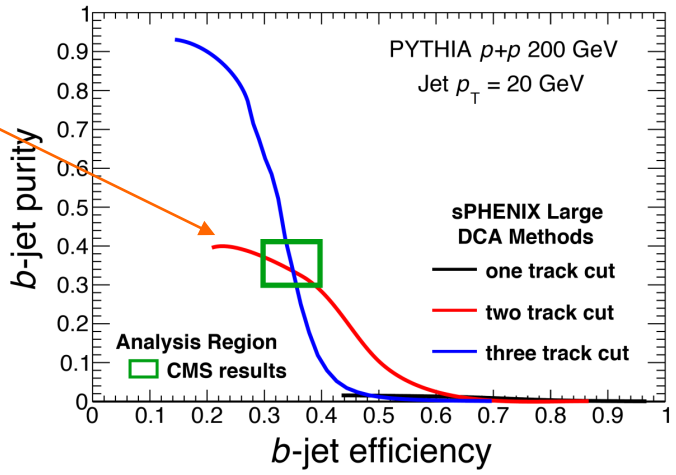
Exploring three leading methods for sPHENIX *b*-jets identification and crosscheck

- Multiple large DCA tracks
- Secondary vertex and kinematic fits
- *B*-meson tagging via semi-leptonic decay or direct invariant mass reconstruction
  - Need volunteer



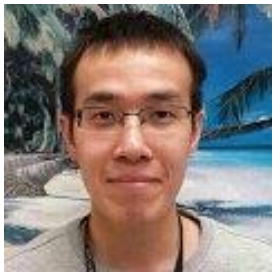


MIE-proposal projection (updated in G4 later slides)

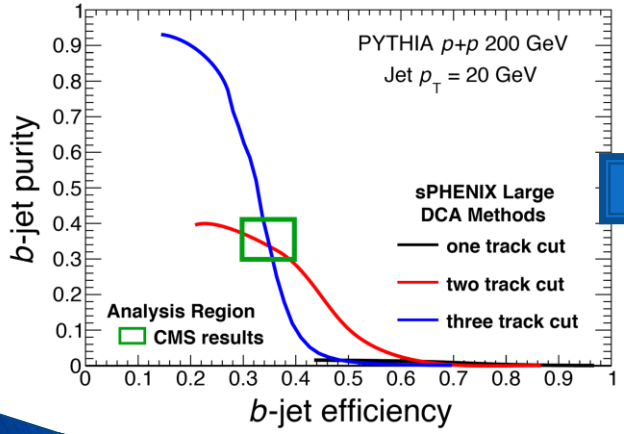


Past activities:
b-jet tagging – High DCA track counting

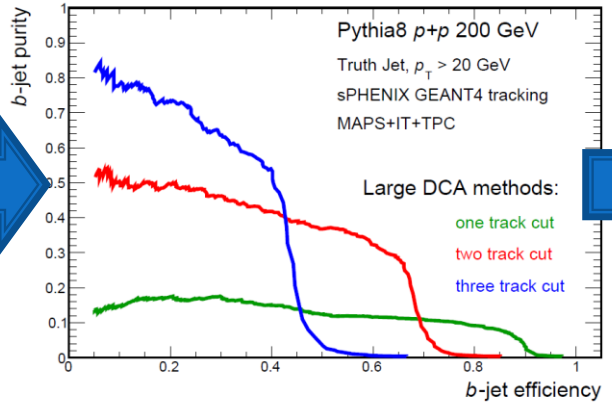
- Short history
  - Dennis and Haiwang implemented track counting tagger in the full Geant4 simulation
  - Haiwang produced projection plot in Geant4 simulation.
  - Systematically validating the Geant4-based track fit procedure, in order to optimize 3-D DCA and likelihood
- Next
  - Reevaluate in HI background with HIJING embedding
  - Optimizing cuts to suppress fake off-vertex tracks



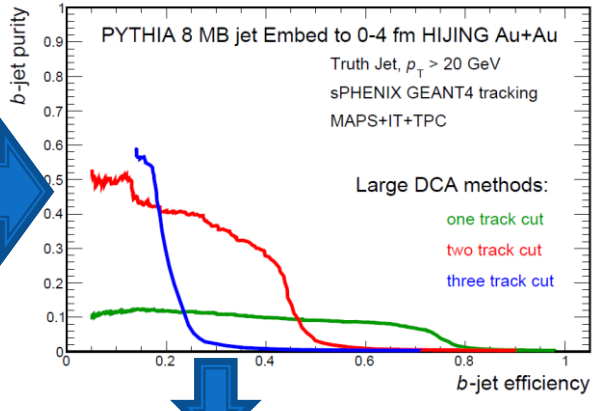
Fast sim in sPHENIX Proposal



Full Geant4 Sim



Exploring 3-D DCA in G4

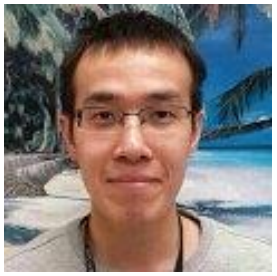


From Haiwang's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1926

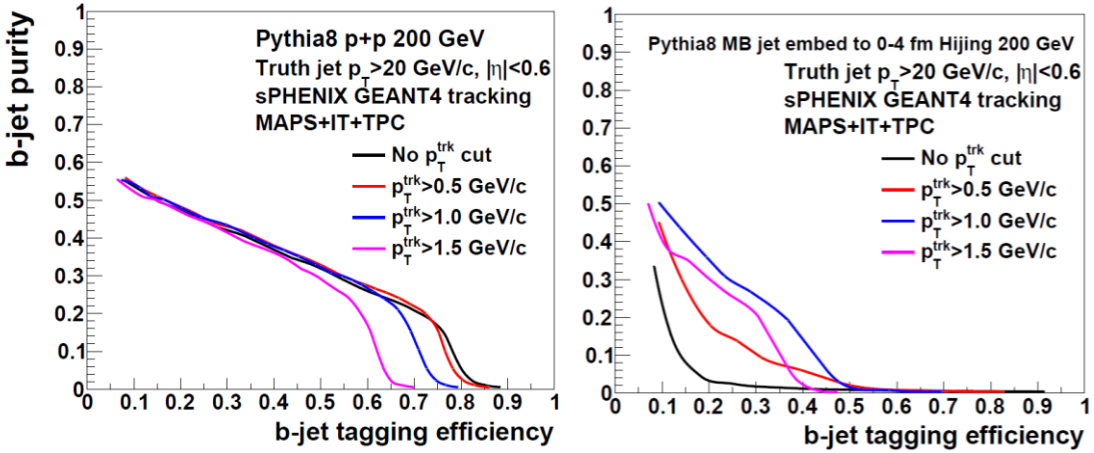
b-tagging performance in HI

Past activities:
b-jet tagging – Secondary vertex

- Short history
  - Haiwang developed new Kalman filter (GenFit2) with vertex finder integration (RAVE)
  - Sanghoon implemented Secondary vertex finder in jet
  - *p+p* performance plot used in tracking review
- Next:
  - Fixing a refitting inefficiency issue (further improve p+p results)
  - Reevaluate in HI background with HIJING embedding

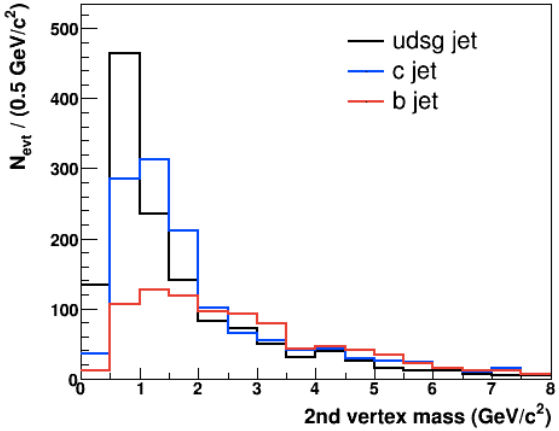


Secondary vertex *b*-tagger



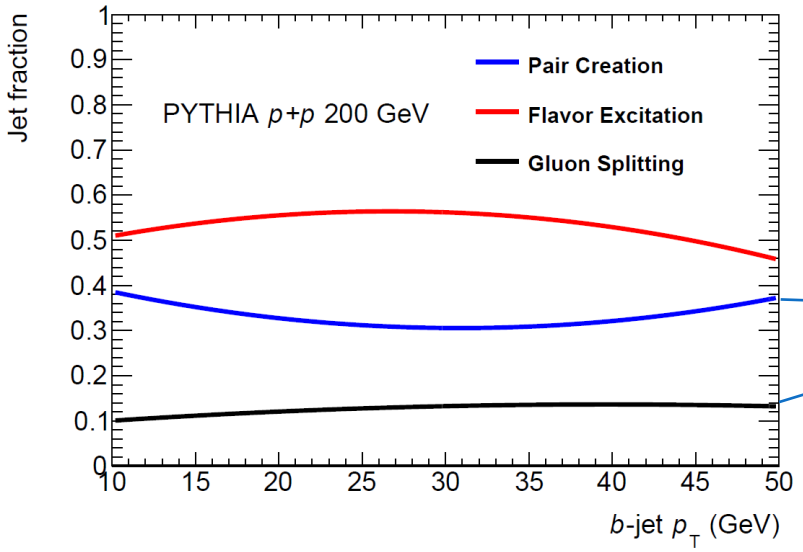
From Sanghoon's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1928

Secondary vertex kinematics fits
Data driven *b*-jet purity estimation

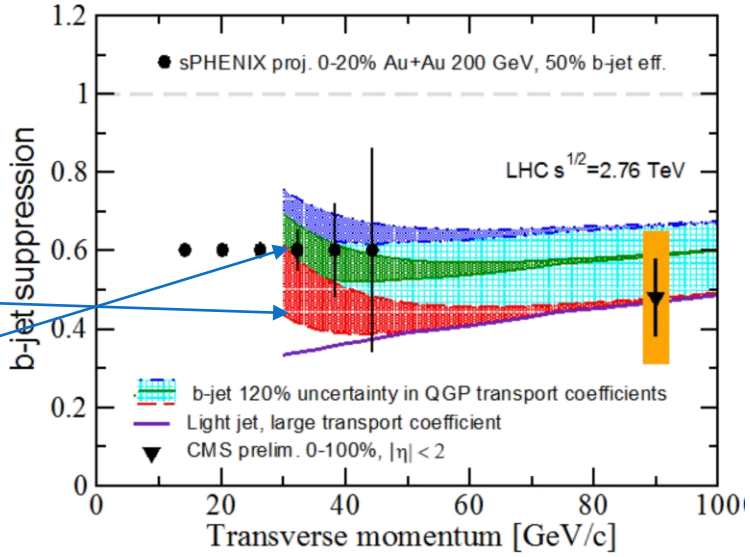


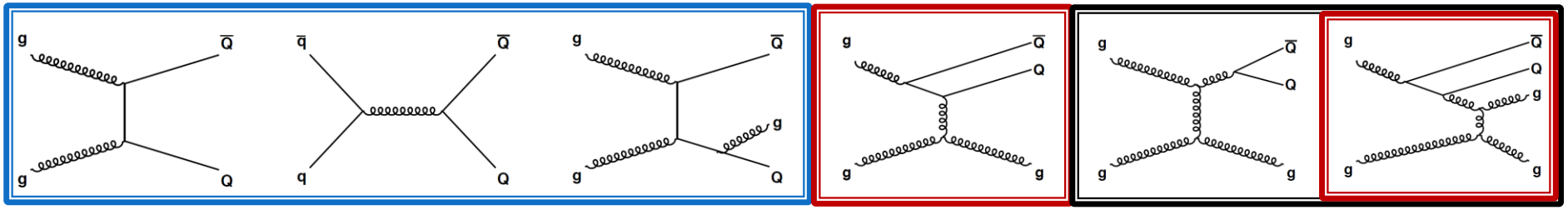
An vulnerability (opportunity) of HF-probes

sPHENIX scientific proposal



CMS, Phys.Rev.Lett. 113 (2014)
Phys.Lett. B726 (2013) 251-256

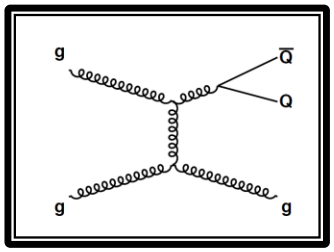


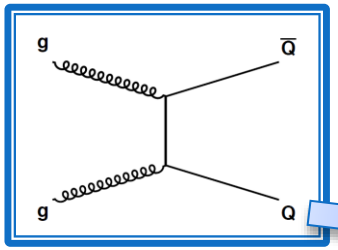


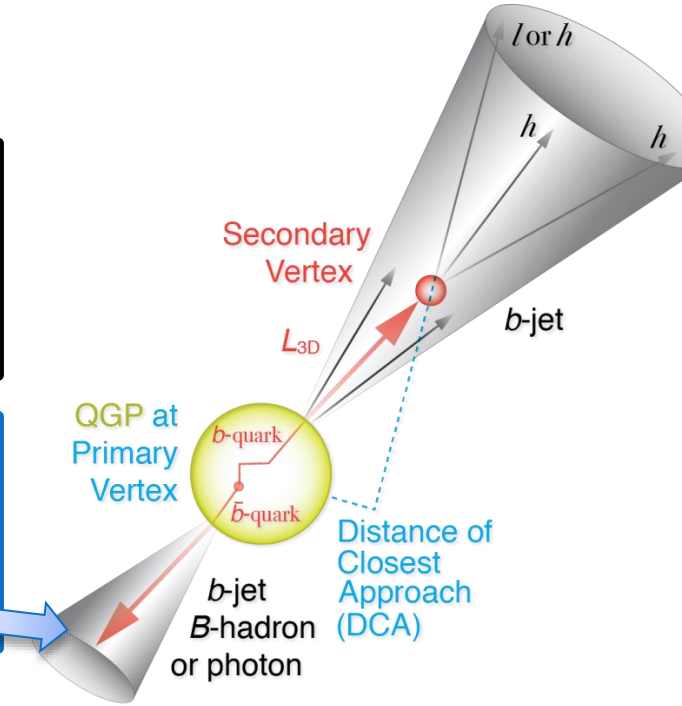
Lund String, Eur. Phys. J. C 17, 137–161 (2000)

b-quark jet selection: *b*-jet correlation

- Event topology to select *b*-quark jet
  - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- sPHENIX provides good acceptance on *b-di*-jet and *b*-jet – non-prompt-*D* correlations
- Helps on purity of jet and *b*-tagging too
- Near term goals: fast-sim projections

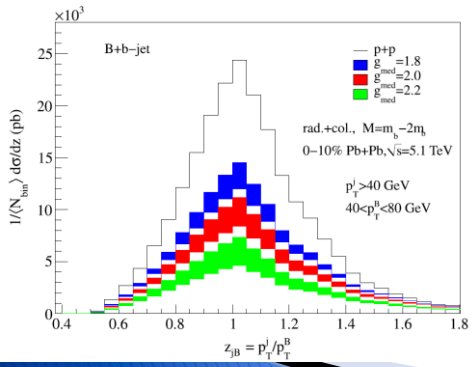






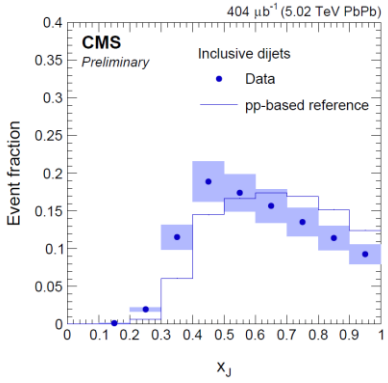
b-jet + *B*-hadron, model

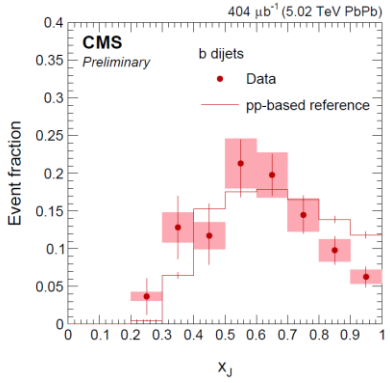
Physics Letters B750 (2015) 287–293



b di-jet, CMS 2016

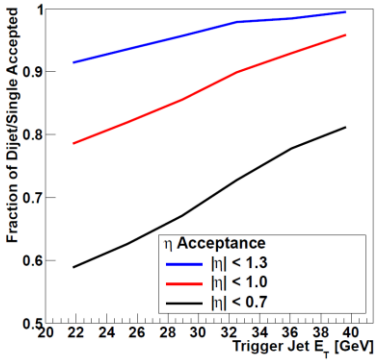
CMS PAS HIN-16-005



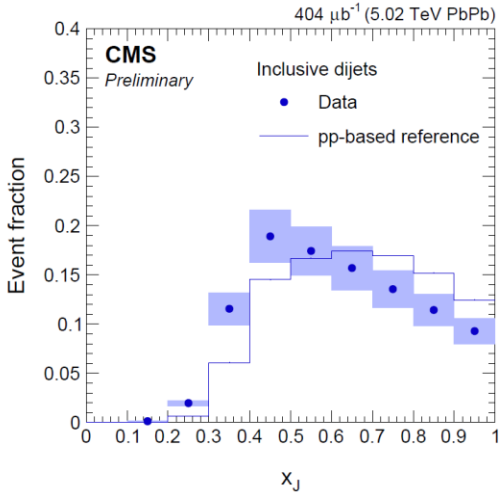


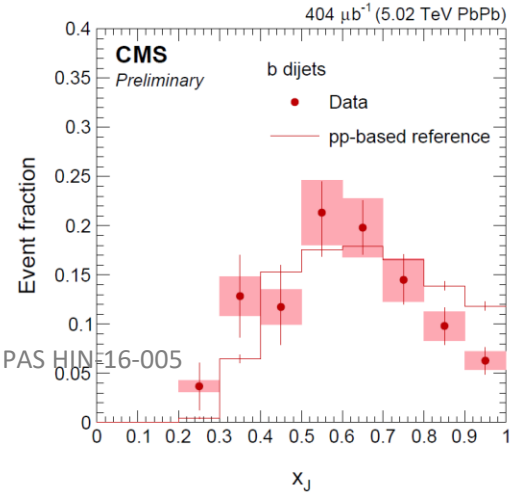
di-jet acceptance in sPHENIX

sPHENIX scientific proposal



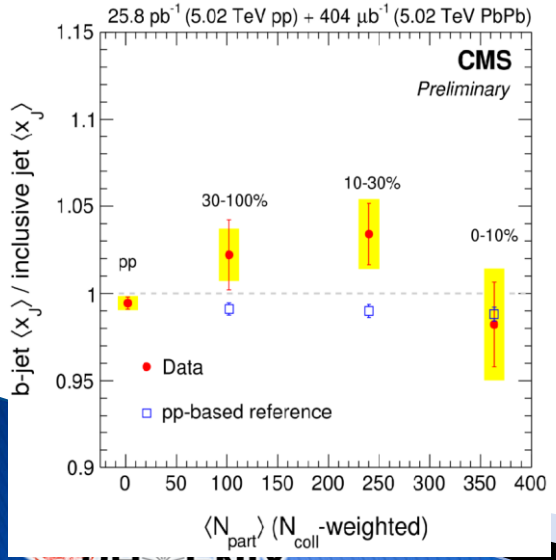
New studies for Di-b-jet asymmetry With reference to recent CMS TN



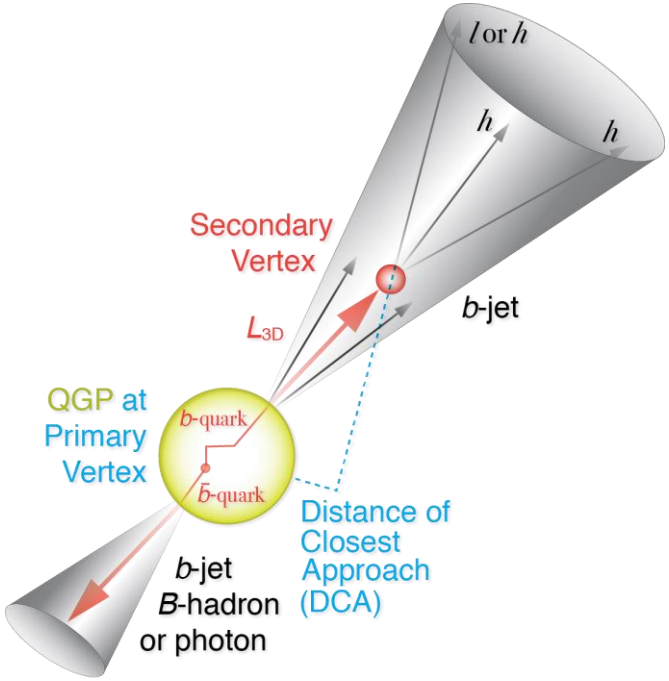


CMS PAS HIN-16-005

CMS-HIN-16-005

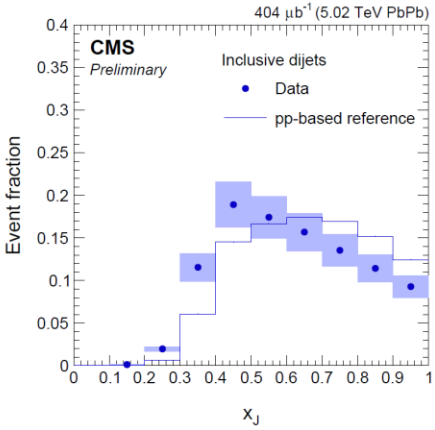


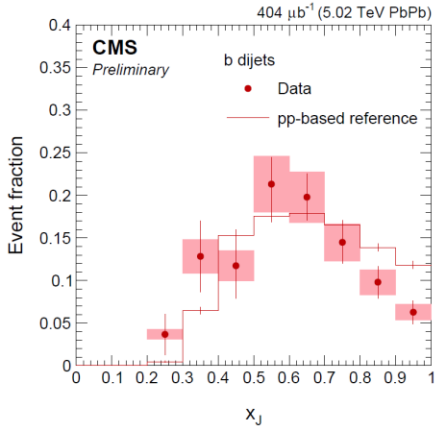
sPHENIX fast sim.



Work started in Jan-2017 workfest
sPHENIX di-bjet asymmetry,
- Darren McGlinchey (UCB)

Di-*b*-jet asymmetry: sPHENIX projection

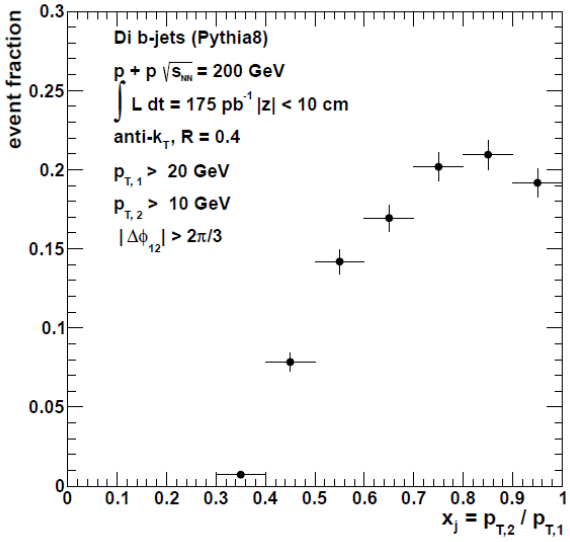


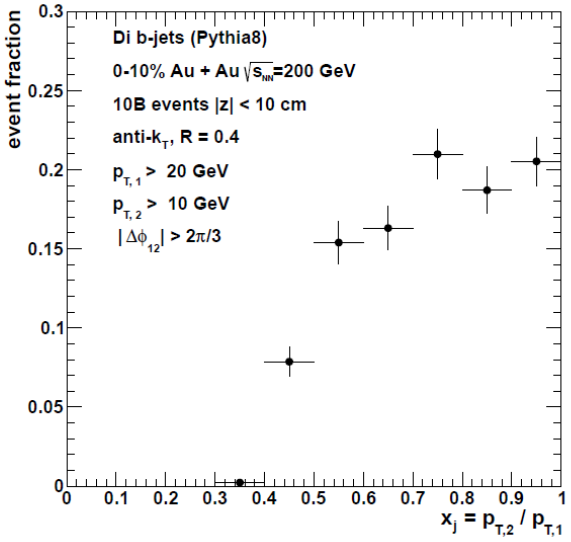


CMS-HIN-16-005, also Yen-Jie's talk July 2016

On-going sPHENIX projection

- By Darren McGlinchey (UCB)
- Pythia8 (HardQCDBBar)
- Fast sim. (truth jets)
- Assuming di-b-jet tagging perf.
  - Efficiency 50%
  - High purity (100%)
- R_{AA} = 0.6 assumed
- sPHENIX proposal lumi. (100B MB)





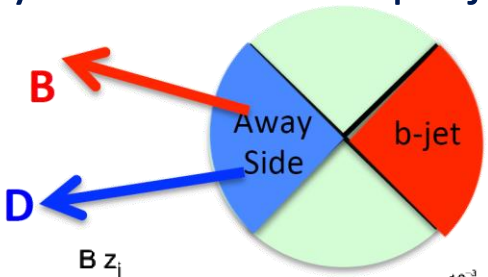
- For $p+p$ use integrated luminosity of $\int \mathcal{L}_{pp}\, dt = 175\ \mathrm{pb}^{-1}$
- For 0-10% Au+Au use $n+n$ equivilent luminosity of $\int \mathcal{L}_{nn}\, dt = N_{evt}^{AuAu} * \langle N_{coll} \rangle / \sigma_{nn} = 10\mathrm{B} \times 962/42\mathrm{mb} = 229\ \mathrm{pb}^{-1}$

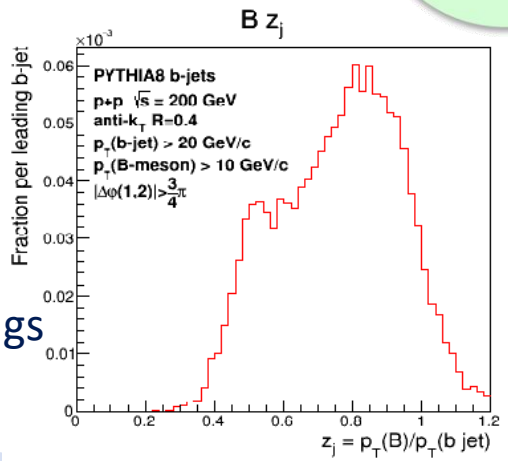
More ideas on *b*-quark jet selection? Non-prompt D-meson tagging

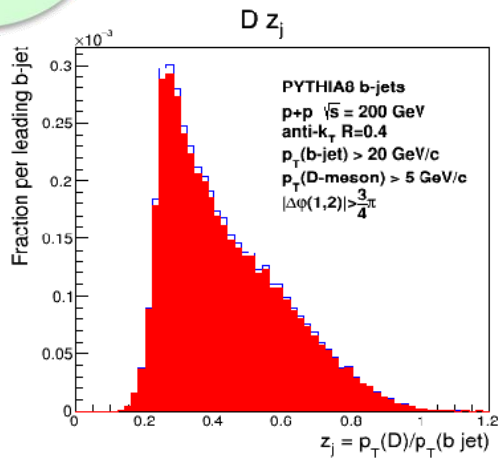
- Xuan Li (LANL) also started investigation of correlation of b-jet in correlation of B-meson or a non-prompt D-meson (→pi + K)
- In jet cone: b->B hadron fragmentation and modification in medium
- In opposite hemisphere: suppression of $g/q \rightarrow b\bar{b}$ jet, enhance *b*-jet tagging purity, p_T-imbalance and constraint energy loss.
- These initial investigations may lead in a set of projection plots for the full proposal

Preliminary study

Updates in simulation meetings



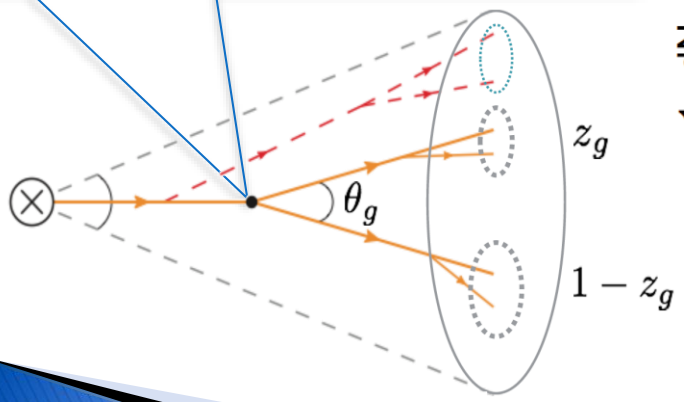




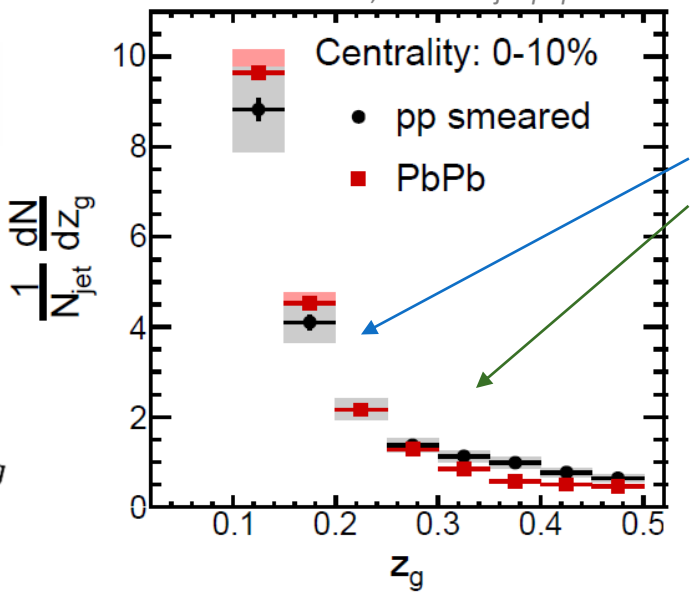
More ideas on *b*-quark jet selection? Jet structure tools

- Jet structure tool developed in HEP adapted in HI field
- Jet grooming observable z_g to separate *b*-quark jet and $g/q \rightarrow b\bar{b}$ jet?
- Mid-term goals: in collaborate with JS TG in developing grooming tools – volunteer welcomed!

Earliest splitting:
More symmetric for $g/q \rightarrow b\bar{b}$ jet?



CMS-PAS-HIN-16-006, inclusive jet *p*+*p* 5.02 TeV



- *b*-quark jets ??
- $g/q \rightarrow b\bar{b}$ jet ??

A+A Modification would enhance z_g~0.5 (i.e. $g/q \rightarrow b\bar{b}$ less suppressed)?

Task planning on HF-jet

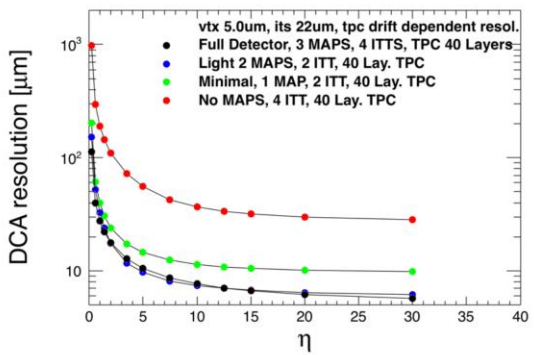
- Realistic implementation in Geant4
  - In verification: implement ladder structure in simulation – Tony F., Gaku M.
  - Need help: digitization of MAPS detector (charge diffusion model, comparison to data, etc.)
- Reconstruction algorithm:
  - By summer (?): complete the pile-up simulation framework – Mike M., Yorito Y.
  - By summer (?): update pattern recognition in the tracking software – Tony forming task force
- b-jet tagging algorithm
  - By summer: Full calorimetry simulation with secondary vertexing tagger – Sanghoon L.
  - By summer: Full calorimetry simulation with high-DCA track counting – Haiwang Y.
  - Help needed: soft-lepton tagging, likelihood analysis
- Inclusive *b*-jet R_{AA}
  - By Apr (?): Update theory curve to RHIC energy – Cesar da S. contact Vitev group
- di-bjet asymmetry
  - By Apr: Apply di-jet purity to projection – Darren M., Haiwang Y.
- *b*-jet-non-prompt-D asymmetry:
  - By Apr: Produce uncertainty projection in fast simulation – Xuan L.
- *b*-jet substructure tools.
  - Need help: exercise jet-grooming algorithm, FF. – in collaboration with Jet Structure group
- *c*-quark jet: charm fragmentation, completes mass hierarchy
  - Need help: try out prompt-D tagger (ALI-PREL-117896) and Corrected Secondary vertex (arXiv:1612.08972)

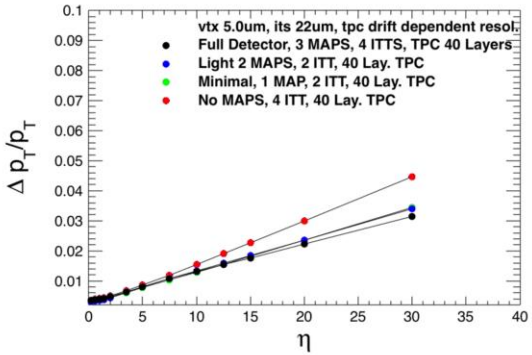
+ discussion in the meeting

Extra information

From Christof R. https://indico.bnl.gov/conferenceDisplay.py?confId=2683

Alternate Detector Configurations



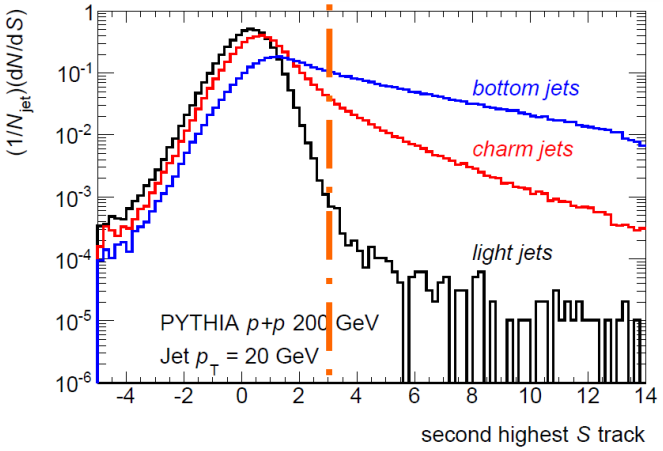


- Alternate detector configurations
  - Default -> 3 MAPS Layers, 4 ITT Layers, 40 Layers TPC
  - Light-> 2 MAPS Layers, 2 ITT Layers to save material budget
    - Slight performance advantage below 10GeV due to lower material budget
  - Minimal -> 1 Maps Layer, 2 ITT Layers, 40 Layers TPC
    - Significant performance decrease (remember 95% hit efficiency per layer)
  - No Maps
    - Likely death sentence for Heavy Flavor program…

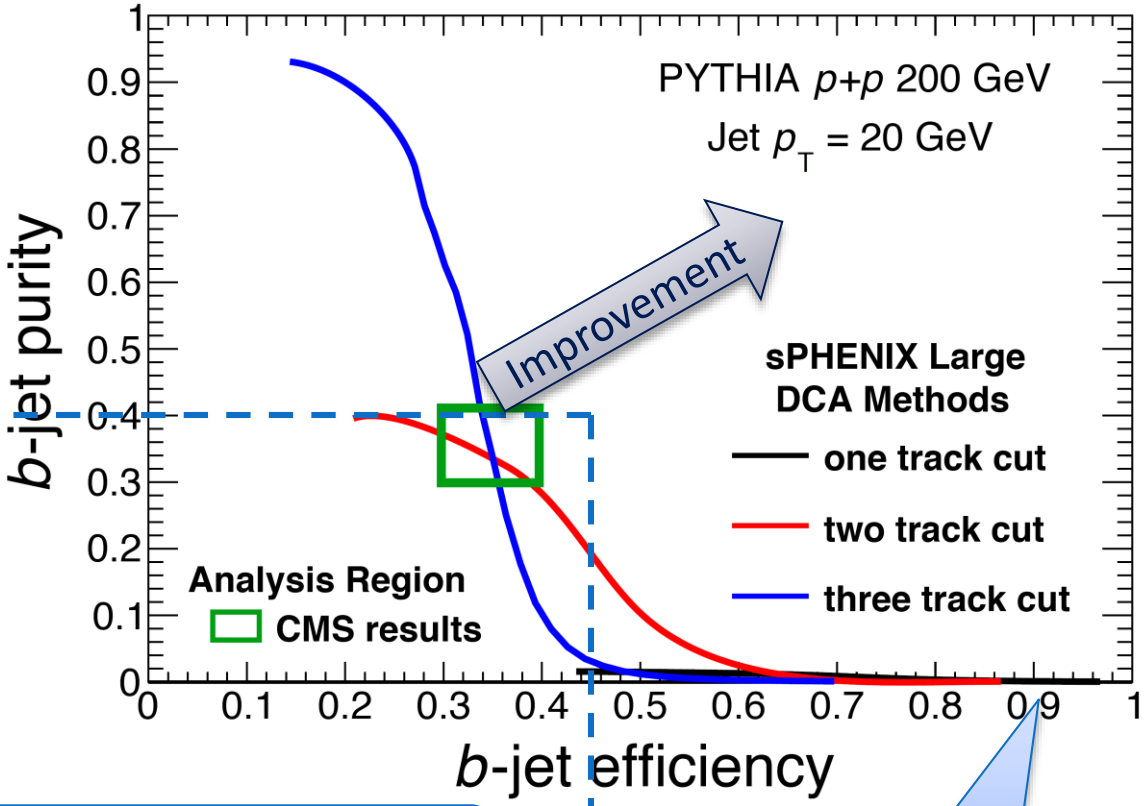
Christof Roland 8 sPhenix Simulation Meeting Mar 07 2016

What affects performance curves

Cut



sPHENIX-proposal projection based on fast sim.
(already updated to Geant4 simulation)



Saturate efficiency at level determined by

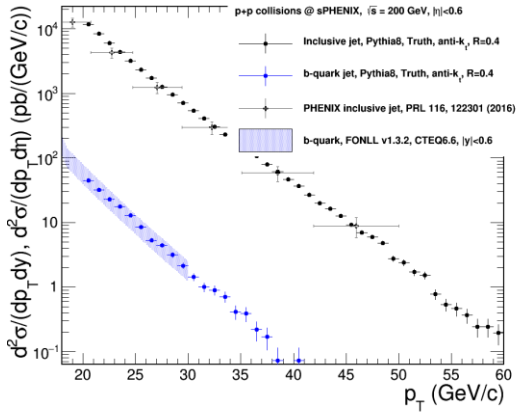
- Control light decay-background
- Fake high DCA (mismatching, alignment) → realistic sim.

Performance turn-on at primary particle's DCA peak
Efficiency improve w/ higher DCA precision and tracking eff.

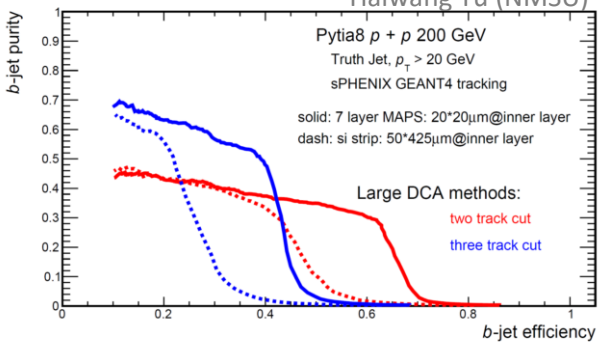
Initial b-jet fraction

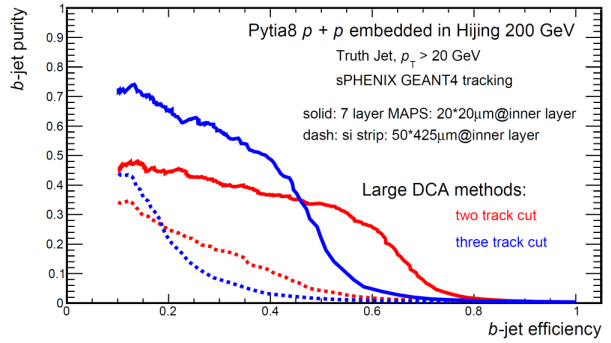
Detector requirement on MAPS/MVTX

- Caveats: there are trade-offs between tail/efficiency/DCA. Important final check is b-jet tagging performance working point: reaching 40% efficiency and 40% purity.
- Low fake high-DCA tail background
  - *b*-jets are rare (0.1%-1%) object identified via displaced vertex, therefore sensitive to rare large-DCA fake track background.
  - The working point of B-jet tagger is few-sigma above DCA peak, and
  - Possible specification: true large DCA track/fake large DCA track > 1:1-1:few for DCA tail integrated from 2-sigma to 1mm
- Tracking efficiency
  - Efficiency for multi-track tagging algorithm is sensitive to (tracking efficiency)^N
  - Possible specification: Require 60% (HFT KPP) – 75% (HFT UPP) single track efficiency p_T>1 GeV/c
- DCA
  - B-jet DCA requirement is relatively moderate
  - Requirement: DCA<100 um @ p_T>4 GeV/c (sPHENIX proposal)
- DAQ output event rate
  - Statistical limited measurement
  - B-jets are jet-structure study based on inclusive jets, require large jet-sample rate
  - Requirement: 15 kHz trigger rate to match sPHENIX DAQ

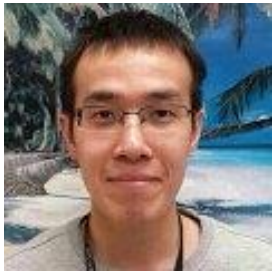


Haiwang Yu (NMSU)





b-jet tagging – High DCA track counting Update in HIJING embedding:

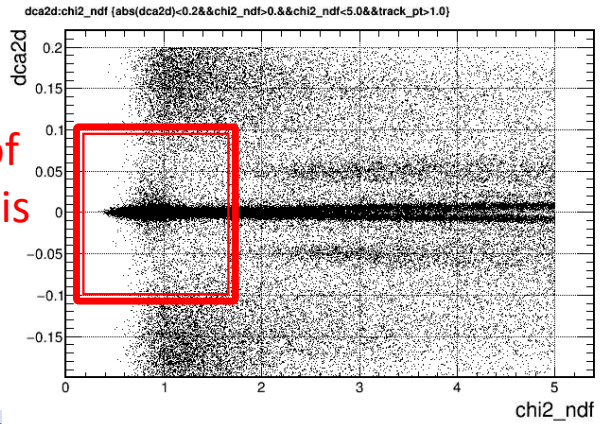


- Haiwang Yu (NMSU) initiated the study by embedding pythia-8 MB jets into 0-4 fm HIJING background, then go through full tracking Geant4 simulation and reconstruction
- Two configuration in study
  - Cylindrically modelled MAPS + INTT + TPC (target configuration)
  - 7-layers of MAPS (Same MAPS inner tracker + MAPS outer tracker) as reference of ultimate tracking configuration of very low fake tracking rate but same physics background.

MAPS + INTT + TPC, p_T>1 GeV/c

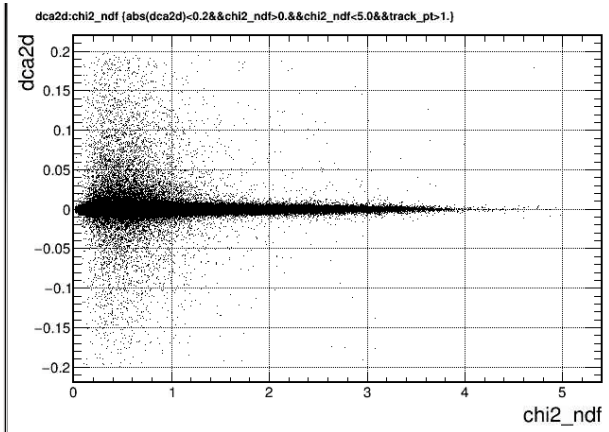
DCA_2D (cm)

Region of analysis



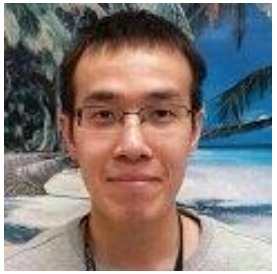
Chi2 / ndof

7-layer MAPS, p_T>1 GeV/c

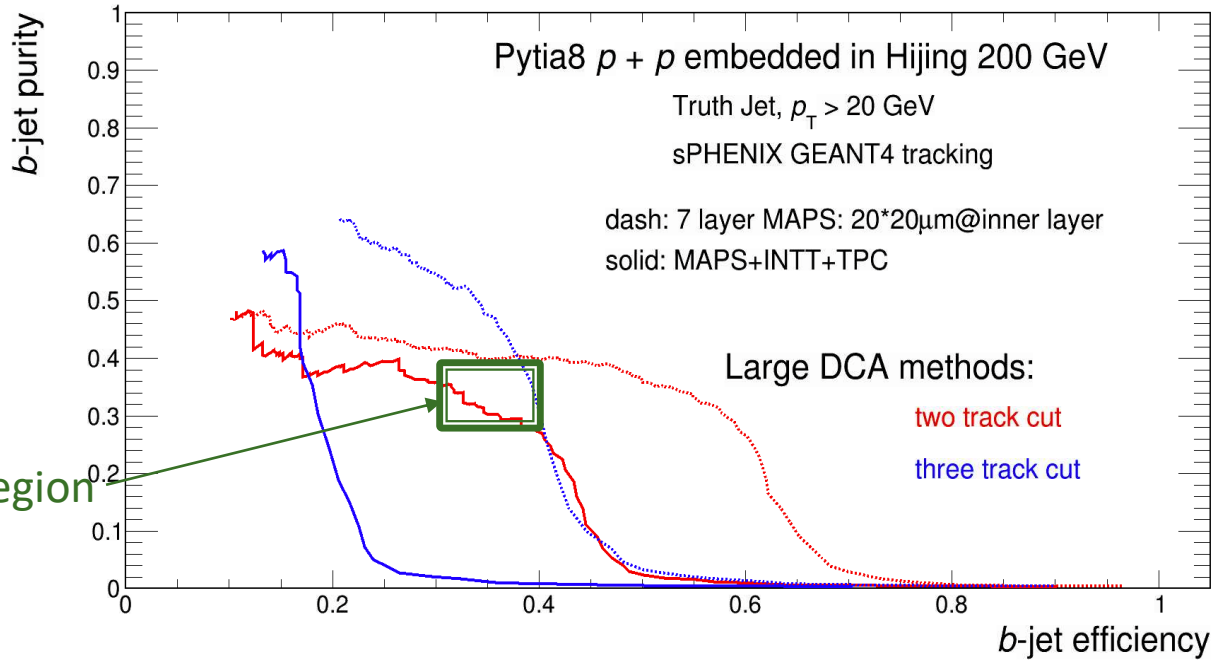


Chi2 / ndof

b-jet tagging – High DCA track counting Update in HIJING embedding:



- Although still in debugging, initial result show 2/3 good tracks reconstructed comparing MAPS+IT+TPC with 7-layer MAPS
- This has implication on b-jet tagging efficiency of reduced signal efficiency
- Preliminary results just made minimal
- Space of improvement: tune cuts, investigating source of large DCA peak and loss of efficiency. Meanwhile, accumulate higher statistics in simulation



CMS analysis region

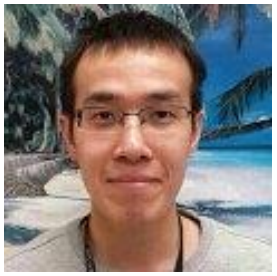
More notes on details:

Pythia-8 MB jet
Embed to 0-4 fm Au+Au
Full tracking in Geant4 and reconstruction

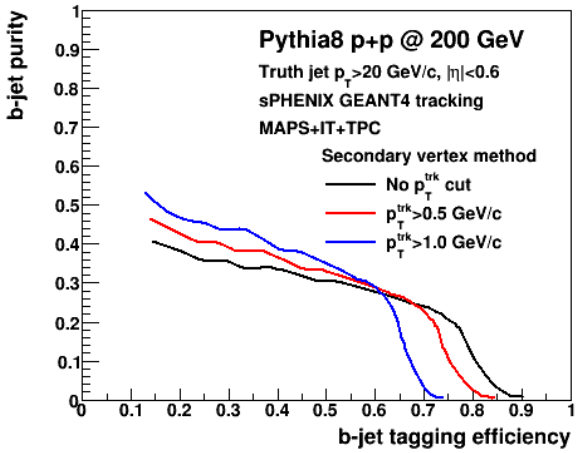
Analysis further require
- Track p_T>1 GeV/c
- Track Chi2/ndof <1.5

Past activities:
b-jet tagging – Secondary vertex

- Short history
  - Haiwang developed new Kalman filter (GenFit2) with vertex finder integration (RAVE)
  - Sanghoon implemented Secondary vertex finder in jet
  - *p*+*p* performance plot used in tracking review
- Next:
  - Fixing a refitting inefficiency issue (further improve p+p results)
  - Reevaluate in HI background with HIJING embedding

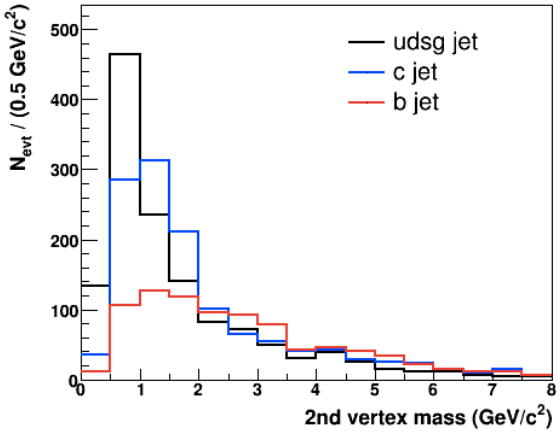


Secondary vertex *b*-tagger



From Sanghoon's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1928

Secondary vertex kinematics fits
Data driven *b*-jet purity estimation

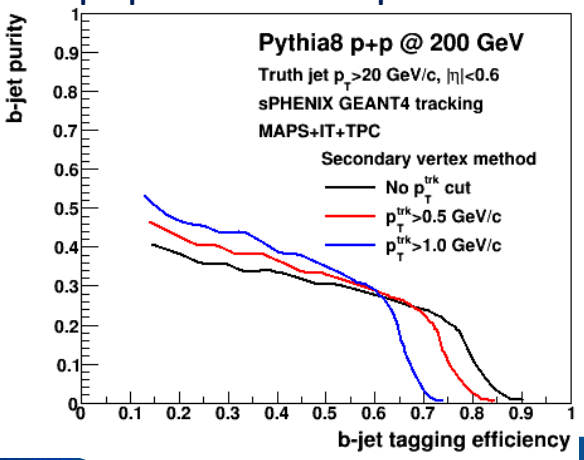


b-tagging performance in HI

b-jet tagging – High DCA track counting Updates and HIJING embedding:

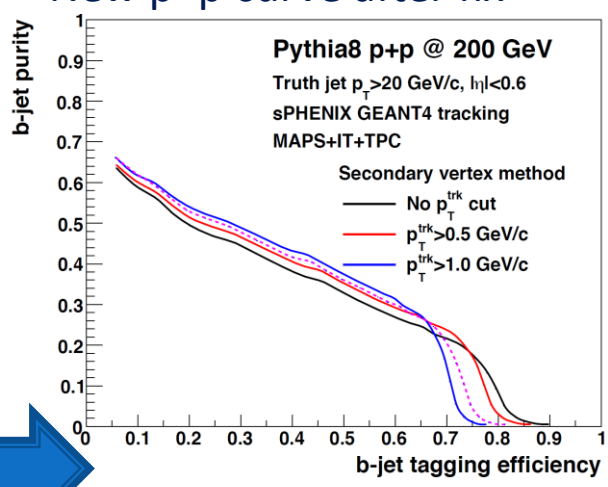
- Sanghoon and Haiwang found an inefficiency in track fitting software (GenFit2, used by expert only), fix submitted. Analysis show improved performance in p+p
- Sanghoon also started embedding study with p+p jets embedded in central HIJING events.
- Working on results for the target tracking configuration of MAPS+IT+TPC

p+p curve in Sept review



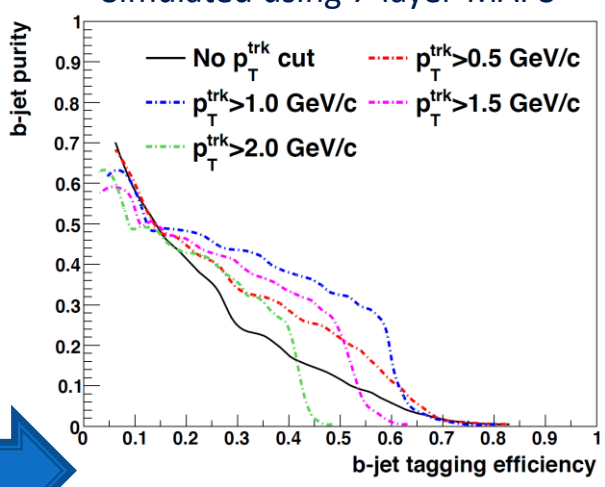
Fitter-inefficiency fix

New p+p curve after fix



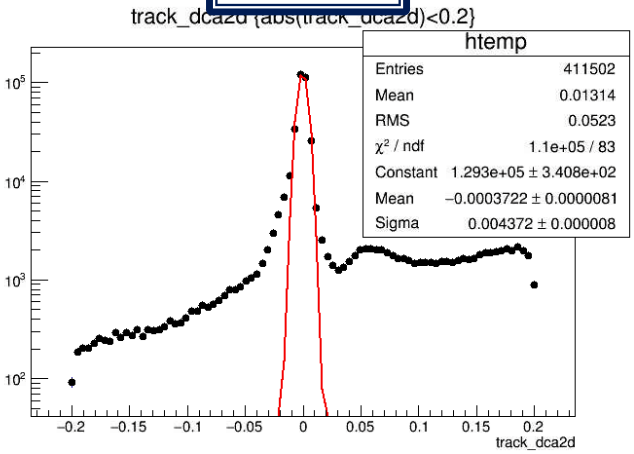
Embedding in central HIJING

Starting HIJING embedding
Simulated using 7-layer-MAPS

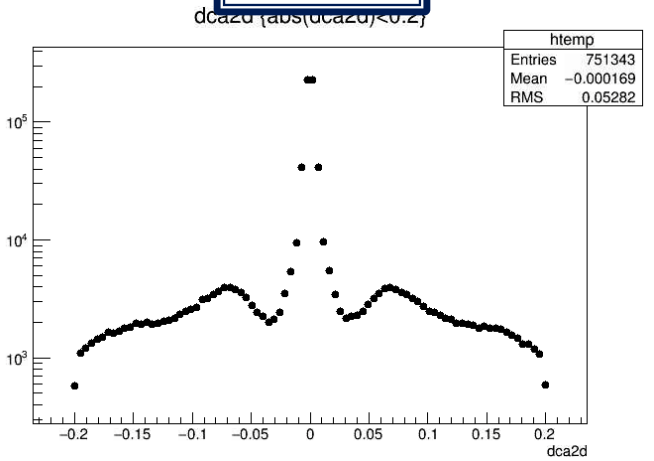


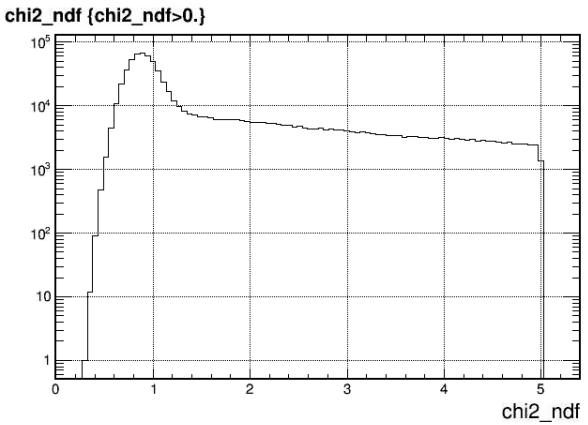
DCAxy shape

Original



Refitting



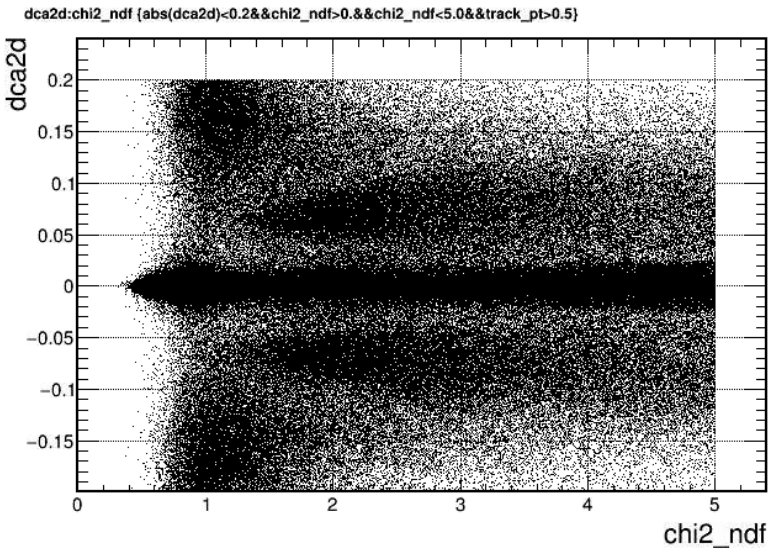


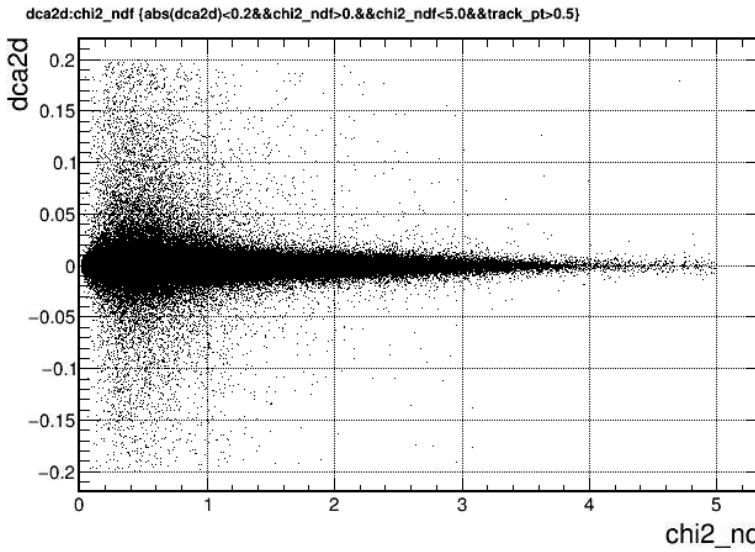
Track selection

MAPS+INTT+TPC

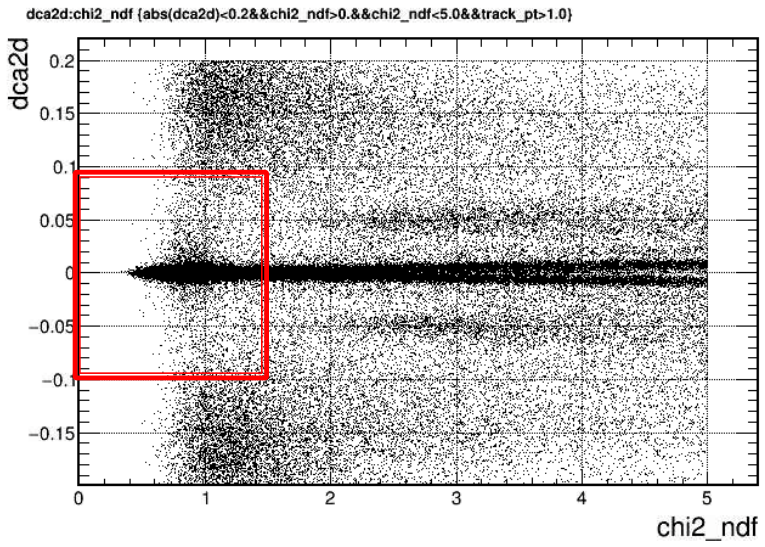
7-Layer MAPS

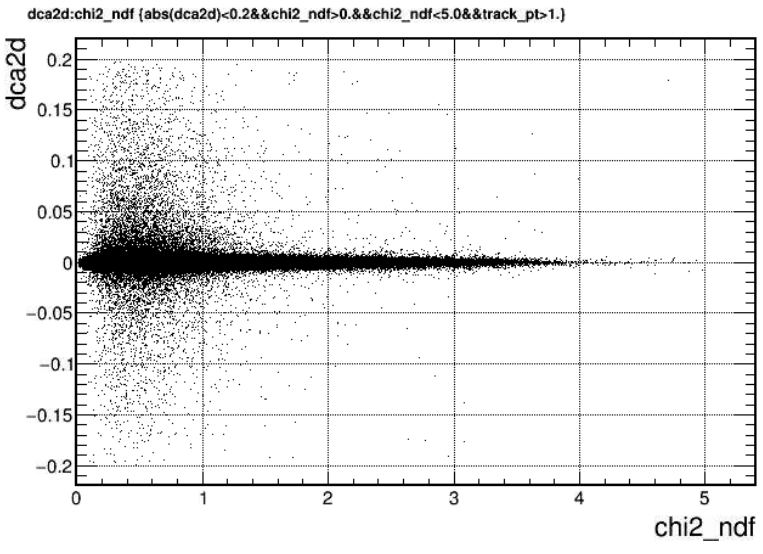
pT>0.5





pT>1.0

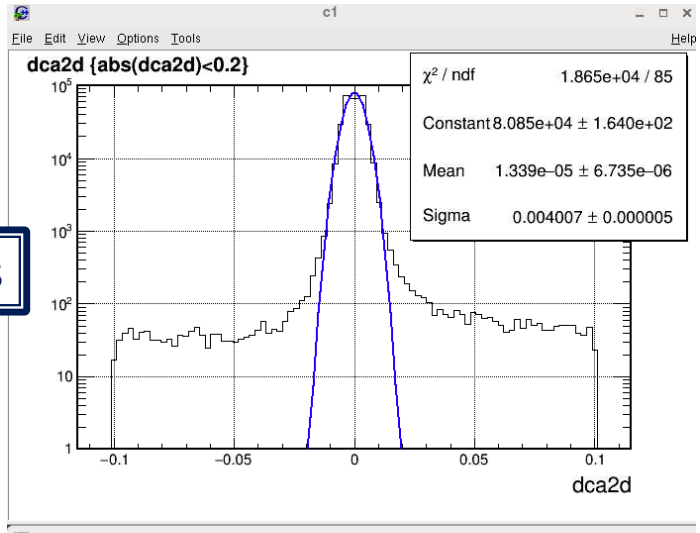




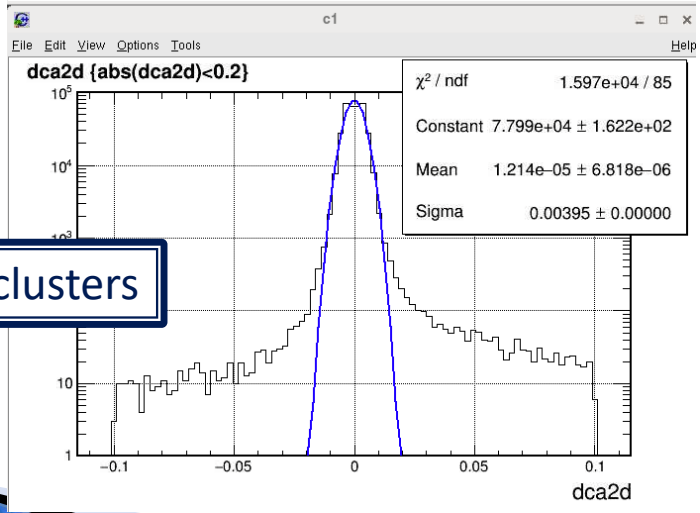
Track selection cont'd

MAPS+INTT+TPC

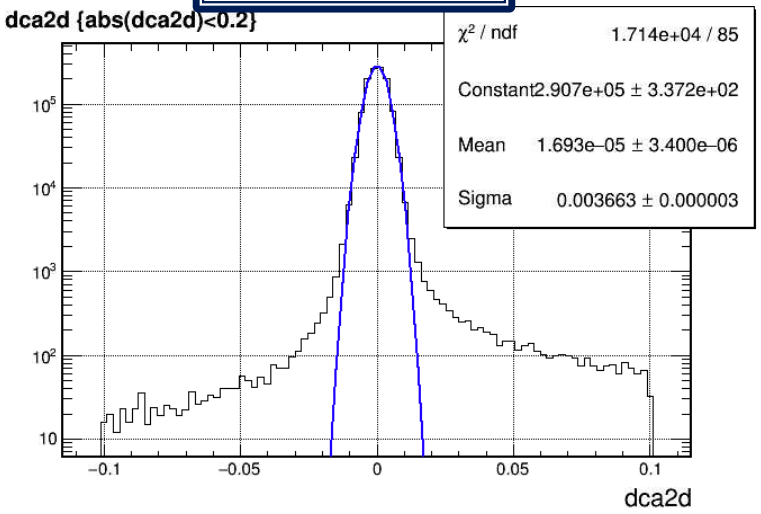
All tracks



No fake clusters



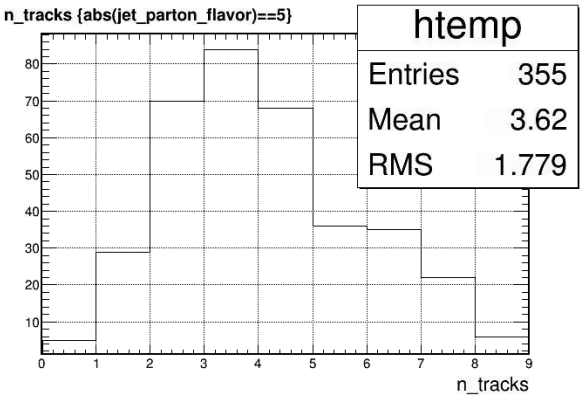
7-Layer MAPS

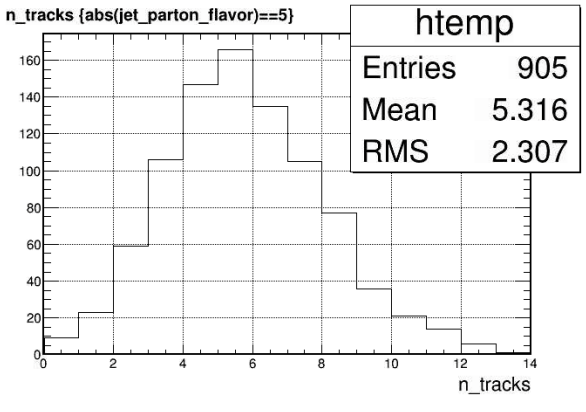


MAPS+INTT+TPC

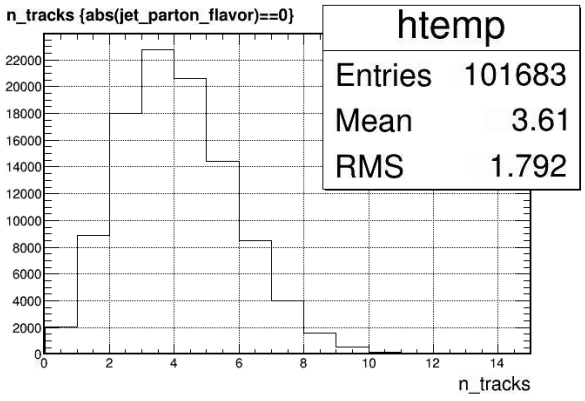
7-Layer MAPS

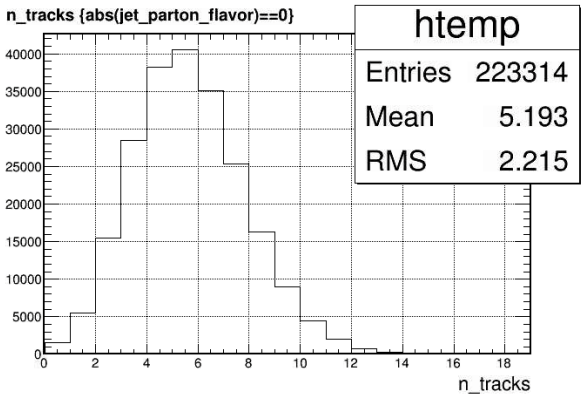
b-jet



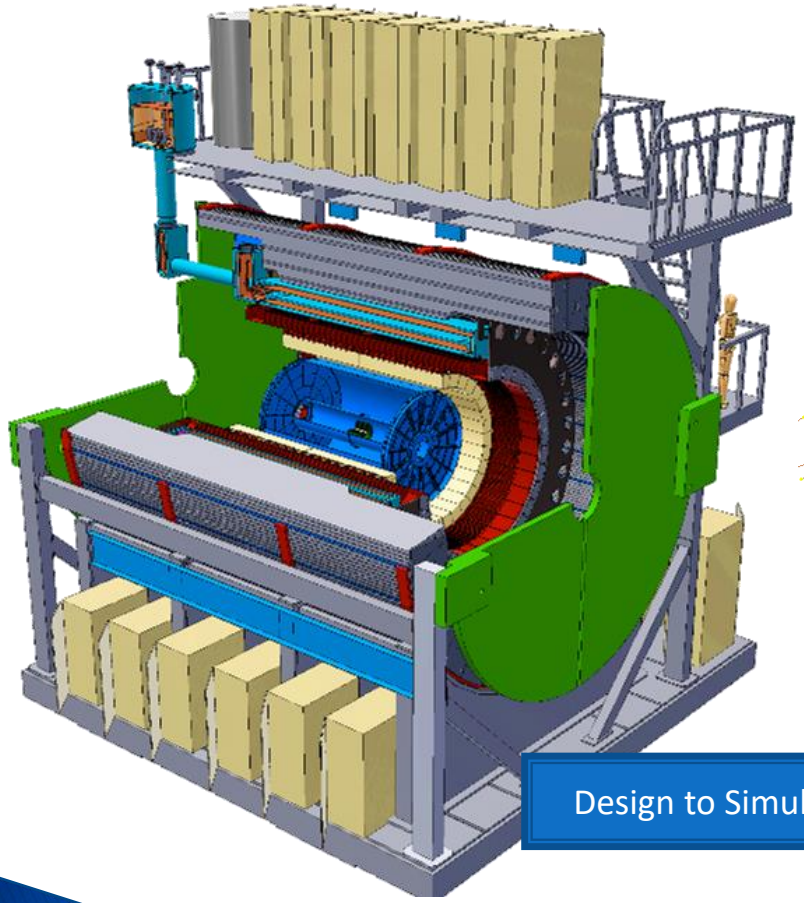


l-jet



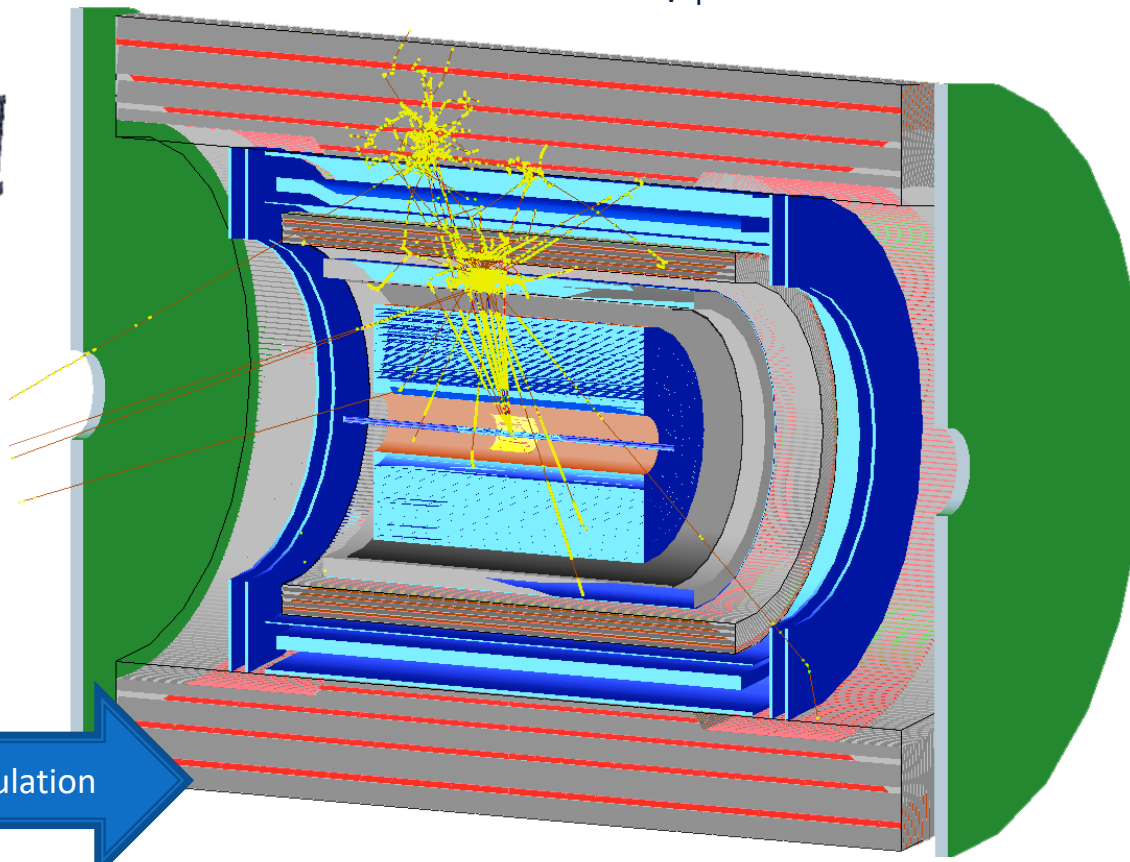


b-jet simulations, drawing to Geant4



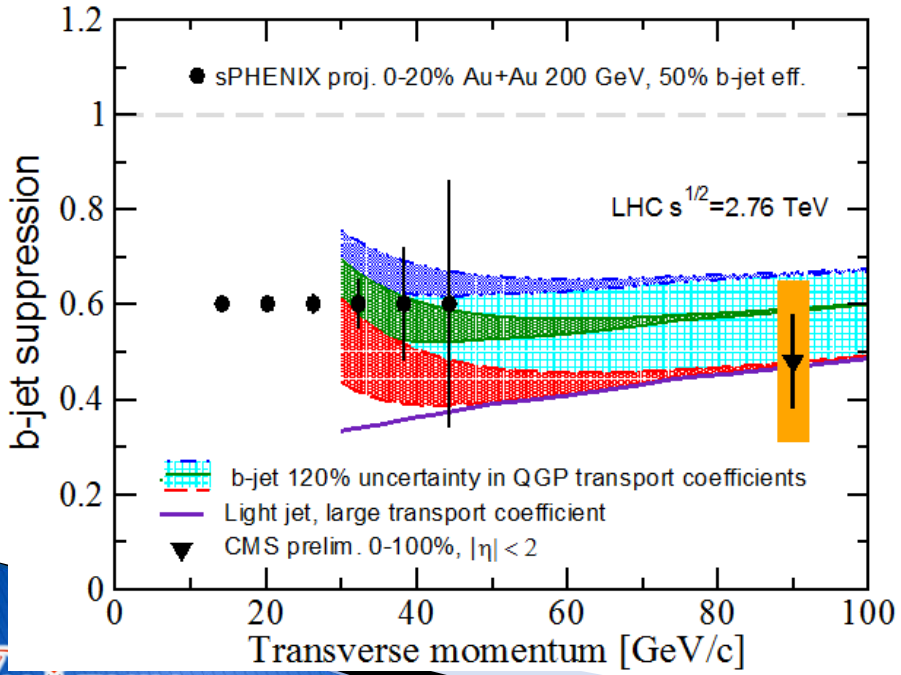
Design to Simulation

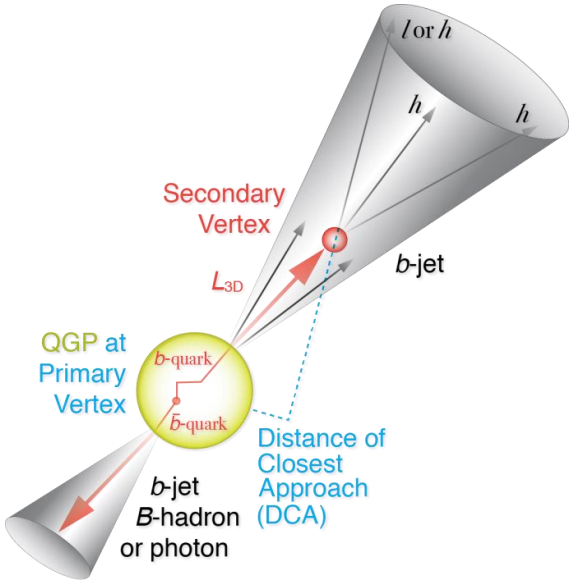
sPHENIX Geant4 simulation of p_T=30 GeV/c B^+-hadron



Luminosity counting

- Current RAA plot assumed 200B MB Au+Au in |z|<10cm
  - 100B MB Au+Au in |z|<10cm assumed for sPHENIX proposal
  - 200B MB Au+Au in |z|<10cm following updated CAD projection
  - Will follow the final luminosity number determined by collaboration for QM17 - Gunther
- For MAPS proposal, we need updated model R_{AA} for RHIC energy

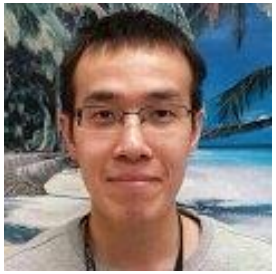


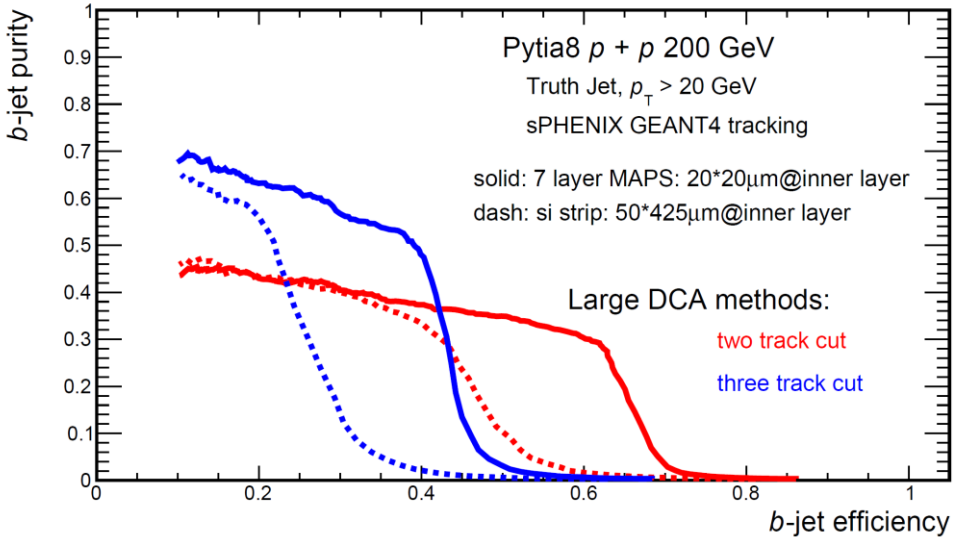


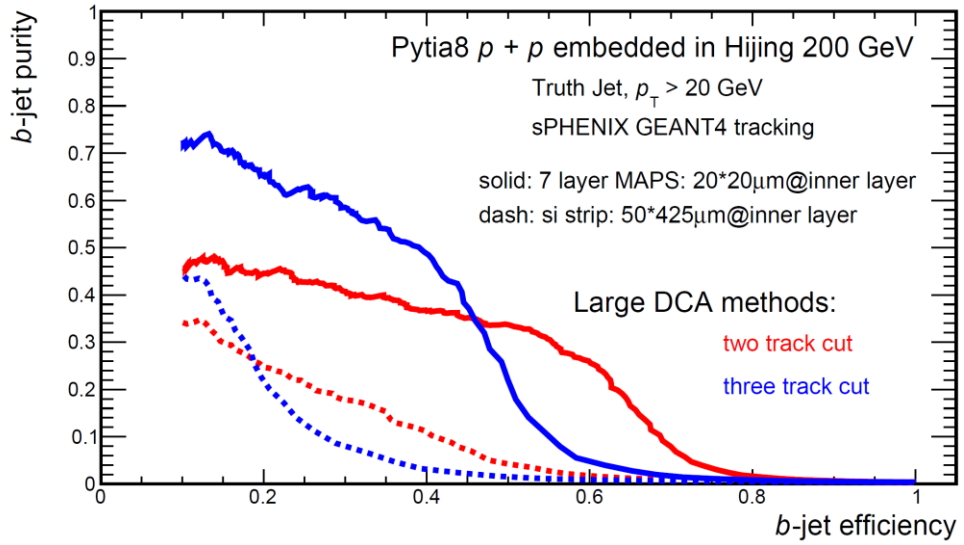
New plots from track counting

- Answering two main questions in this workfest:

1. How we do in HIJING
2. What if we use other technology

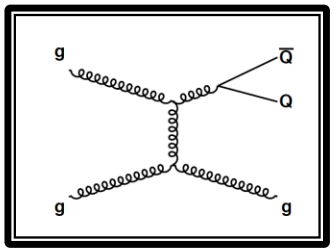


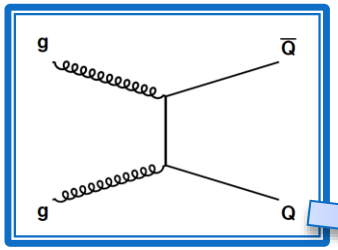


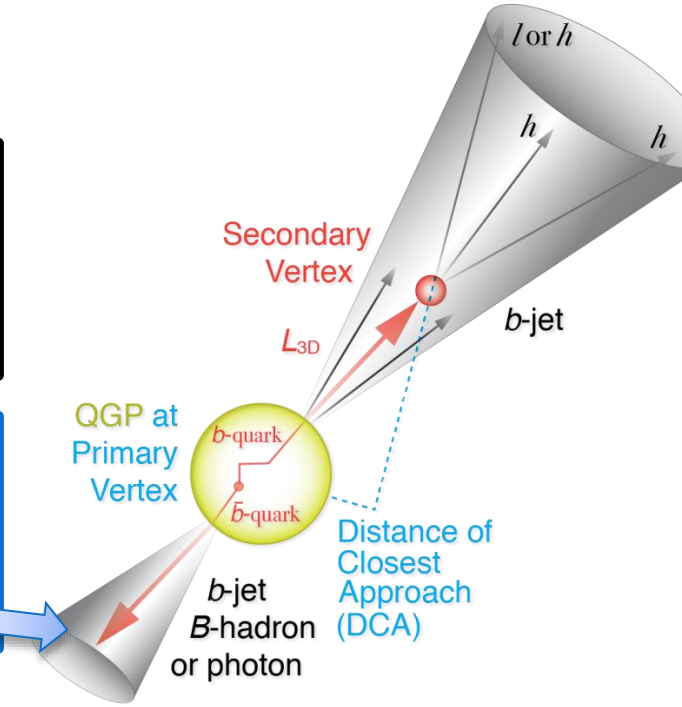


b-quark jet selection: *b*-jet correlation

- Event topology to select *b*-quark jet
  - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- sPHENIX provides good acceptance on *b-di*-jet and *b*-jet – non-prompt-*D* correlations
- Helps on purity of jet and *b*-tagging too
- Near term goals: fast-sim projection







b-jet + *B*-hadron, model

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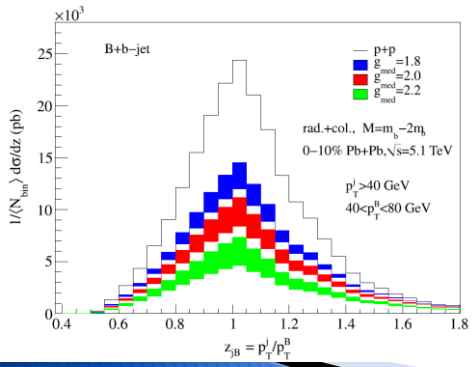
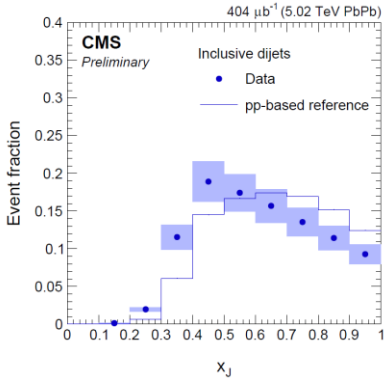
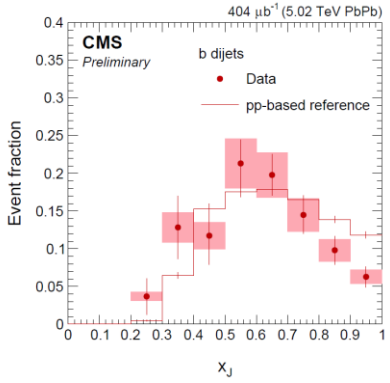


b di-jet, CMS 2016

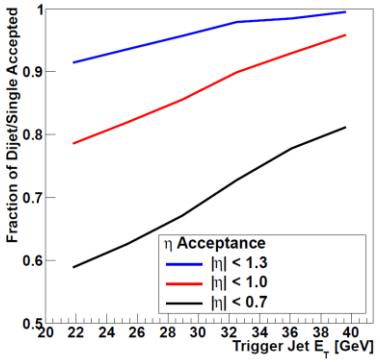
CMS PAS HIN-16-005



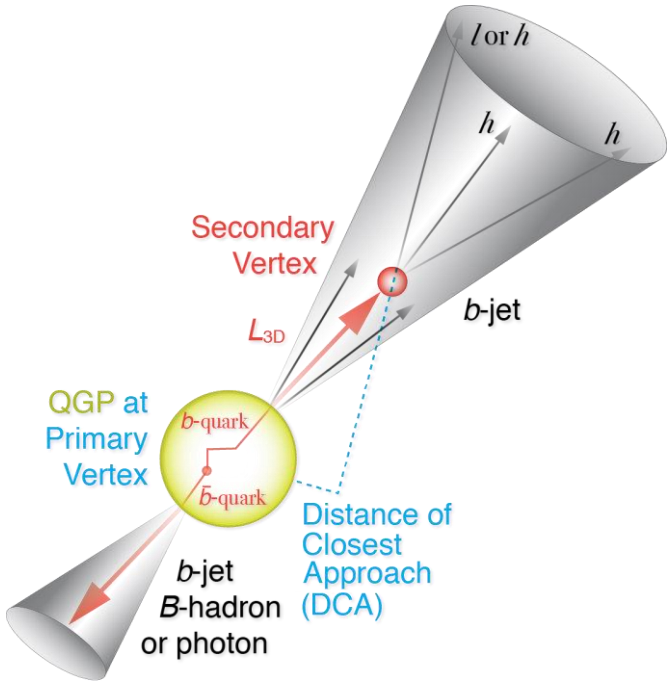


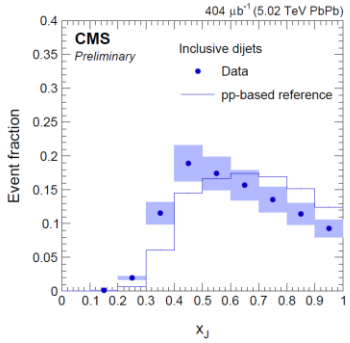
Inclusive *di*-jet acceptance in sPHENIX

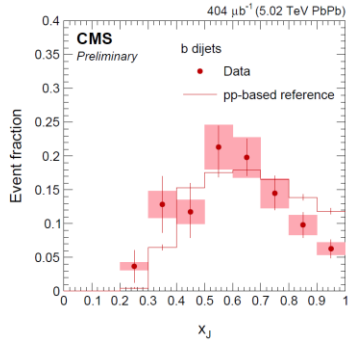
sPHENIX scientific proposal

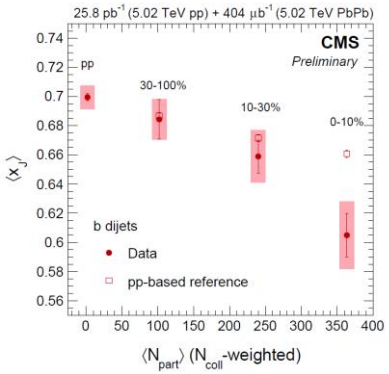


New plots from Di-b-jet asymmetry



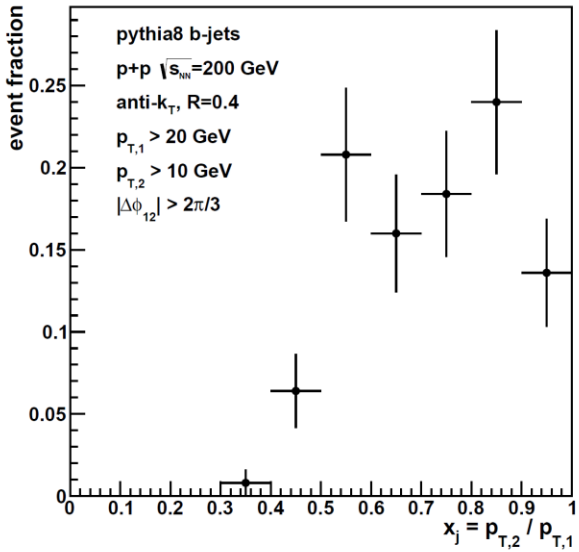


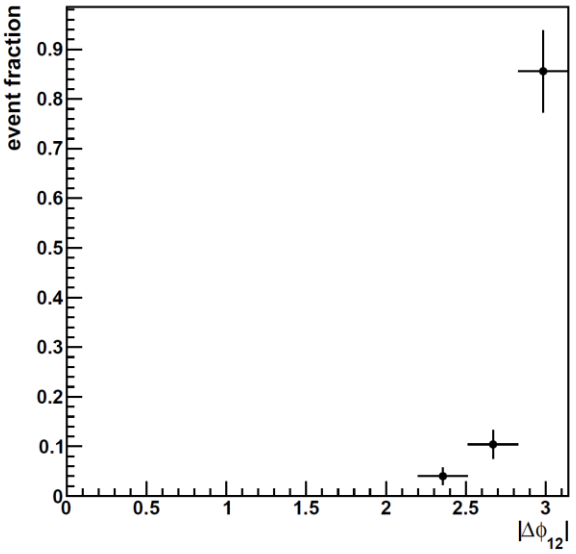


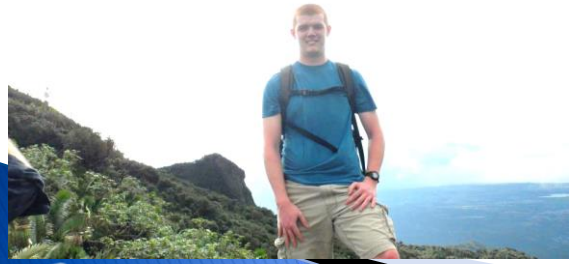


CMS PAS HIN-16-005

Started in workfest : sPHENIX di-bjet asymmetry,
This plot is preview: fast-sim, hardQCD-B, NOT scaled to lumi
- Darren McGlinchey (UCB)





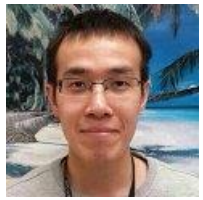


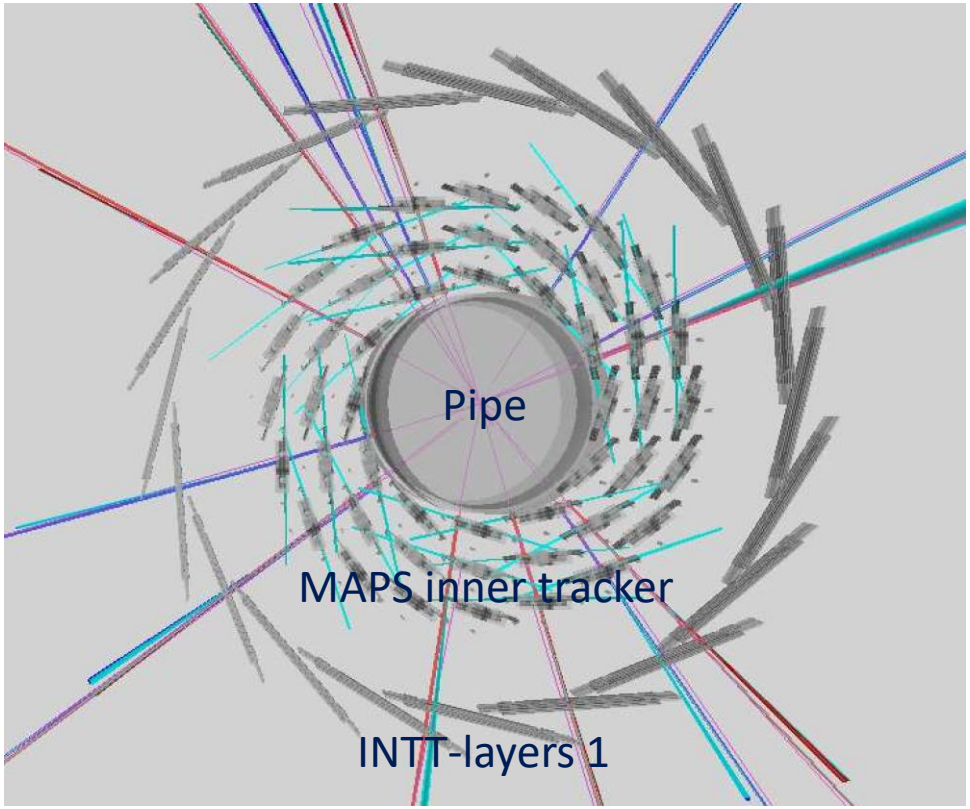
PHENIX

Silicon ladder setup

- Implementing realist geometry in laddered silicon detectors
- Base-code in nightly build
- Tuning on going for
  - INTT ladder thickness
  - Kalman filter to interface with geometry





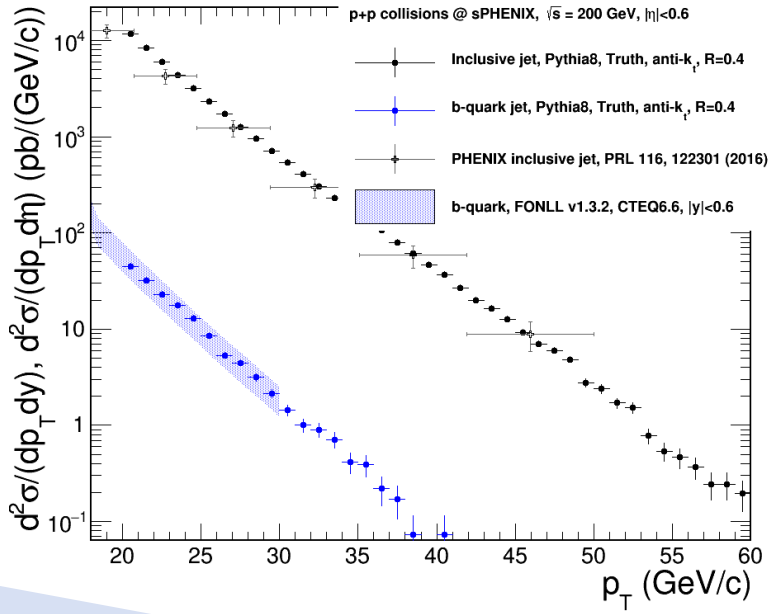


Simulation resources

- Currently we separate jet and b-tagging simulations to help speed up simulation. Need to verify factorization in the next stage
- Simulation setup used in analysis:
  - Tracking simulation in p+p in MAPS+IT+TPC (few minute / event)
  - Tracking simulation in HIJING + embedding for 7-layer MAPS (few minute / event, used for initial tunings) and for MAPS+IT+TPC (1-hour / event, use for performance plots)
- In developments
  - Silicon detectors in ladder geometry <- make available soon?
  - Pile up simulation <- make available soon?
  - TPC distortion corrections

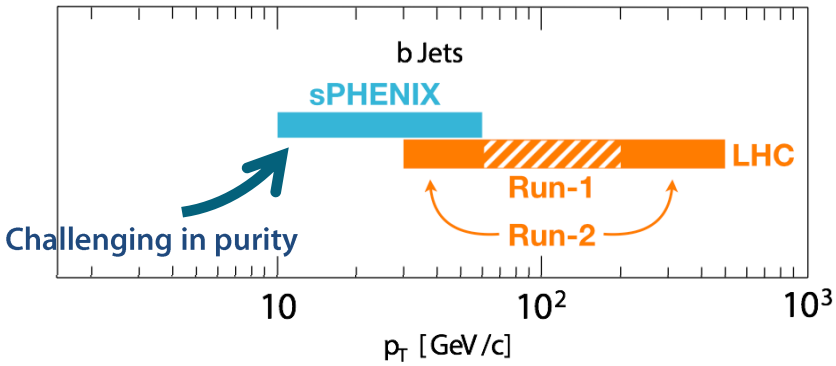
Jet flavor definition tools

- Unifying truth definition and jet sample generations
  - Based on Dennis' work defining a truth tagging module run on MB events to synchronize *B*-jet definition and yield between analyzers
  - Two options provided in defining truth jet by matching *b*-quark in jet (CMS definition) or by matching *B*-hadron in jet (proposal definition)
  - Available on GitHub: https://github.com/sPHENIX-Collaboration/analysis/tree/master/HF-Jet/TruthGeneration
- In collaboration with TS TG: Plan to be generalized to light-parton tagging and parton interaction channel categorizations
- Mid-term goal: cross checked with data and NLO generators

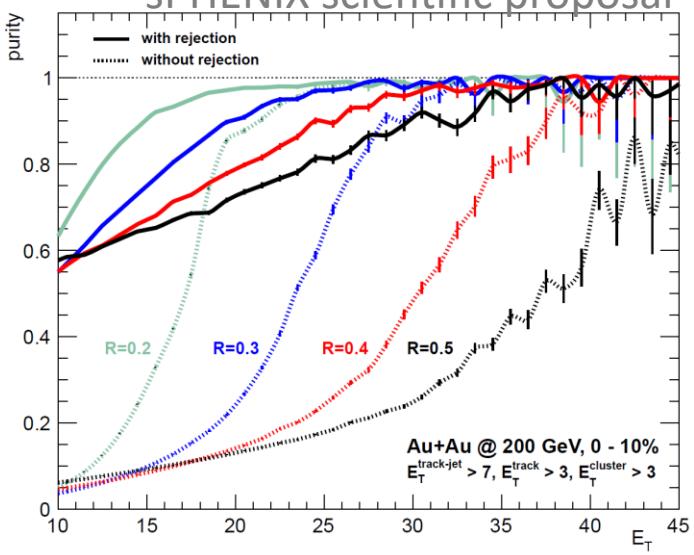


Jet finding and fake rejections

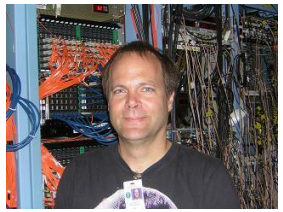
- HF-jet are based on jet, relying on jet finding development lead by JS TG
  - Emphasis on purity and reach to lowest-possible-p_T jet, where mass effect is maximized
  - No statistics for *b*-jet beyond $p_T > 50$ GeV/c
- HF-jet specific: response in detector for *b*-favored jet, unfolding and media modification
  - Require join study with JS TG in term of experience and toolkit developments

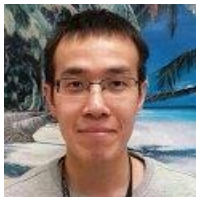


sPHENIX scientific proposal



HF-jet TG high priority longer-term tasks



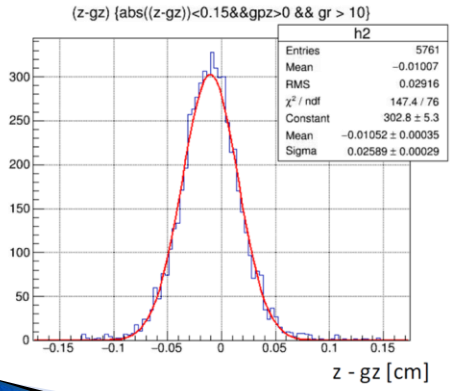
- Goal: realistic study of HF jet performance in sPHENIX simulation and reconstruction.
- High priority development tasks :
  (current developers and your help/ideas welcomed!)
  - Realistic implementation in Geant4
    - Tony F./Gaku M./Chris P.: merged to main repository last week. Validating for general use.
  - Generalized Kalman filter
    - Haiwang Y./Chris P., ready, used in analysis, improving details
  - Multi-vertexing/*b*-tagging via secondary vertexing in jet
    - Sanghoon L./Haiwang Y.: ready, used in analysis, push towards HI analysis
  - *b*-jet tagging: Track Counting
    - Haiwang Y./Dennis P.:
      ready, used in analysis, push towards 3-D DCA and HI analysis
  - *b*-jet tagging: Soft Lepton Tagging, exploratory
  - *b*-quark jet selection: *B*-Meson Tagging. Exploratory, volunteers from LANL and LBNL
- Area of overlapping with to other TG groups
  - JS TG: Jet detection / modern jet structure tools / event and jet flavor tagger
  - Quarkonia TG: tracking development/ HF-meson detection

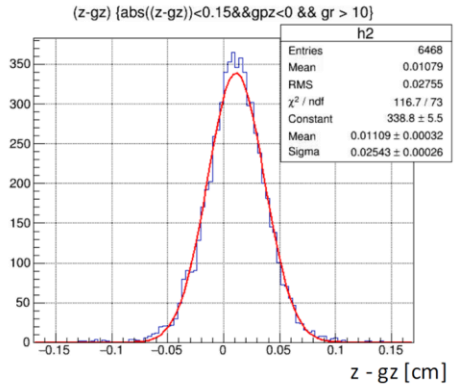
Highlight recent activities: DCA_x

- Both methods highly depending on quality of DCA
- Haiwang *et al* developing capable Kalman filter (GenFit2), expand to DCA_{3D} and use it to validate
- Not only-MAPS matters for DCA
  - Consider use z-sensitive strip in subset layers of INTT?
  - Important to develop and verification as a whole system downstream of clustering

Small (but systematic) bias in TPC cluster z

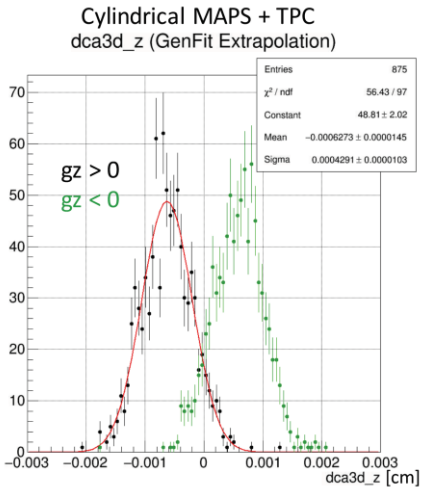
TPC software group is fixing this problem





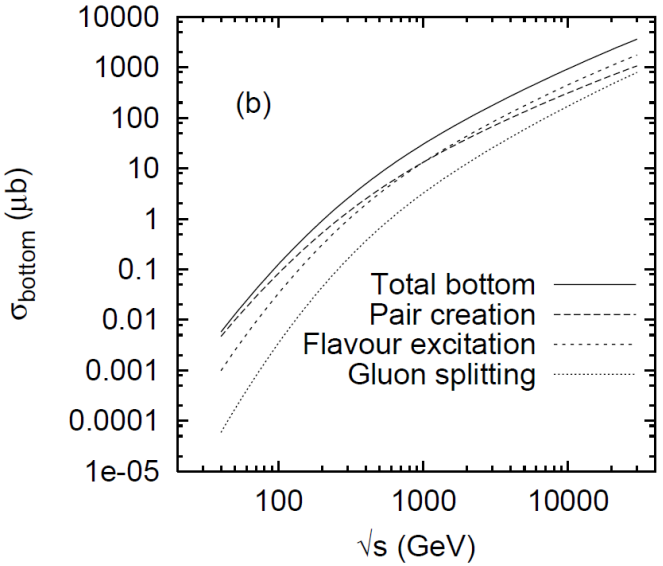
Kalman fit with MAPS

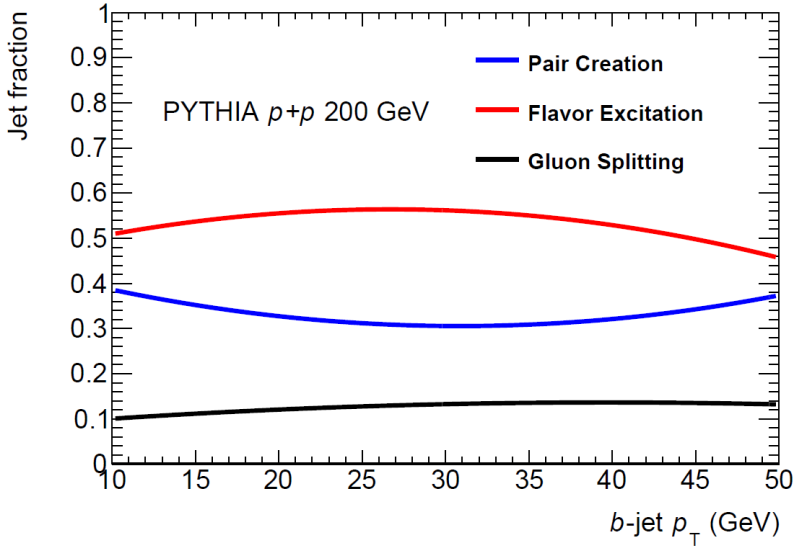
Non-negligible bias in DCAz



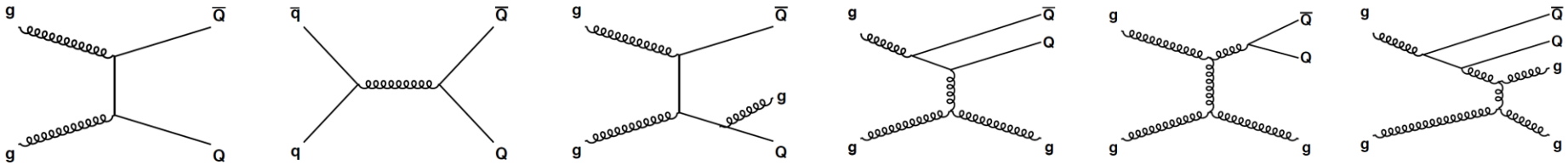
From Haiwang's talk https://indico.bnl.gov/conferenceDisplay.py?confId=1940

b-jet fraction in LUND family estimation

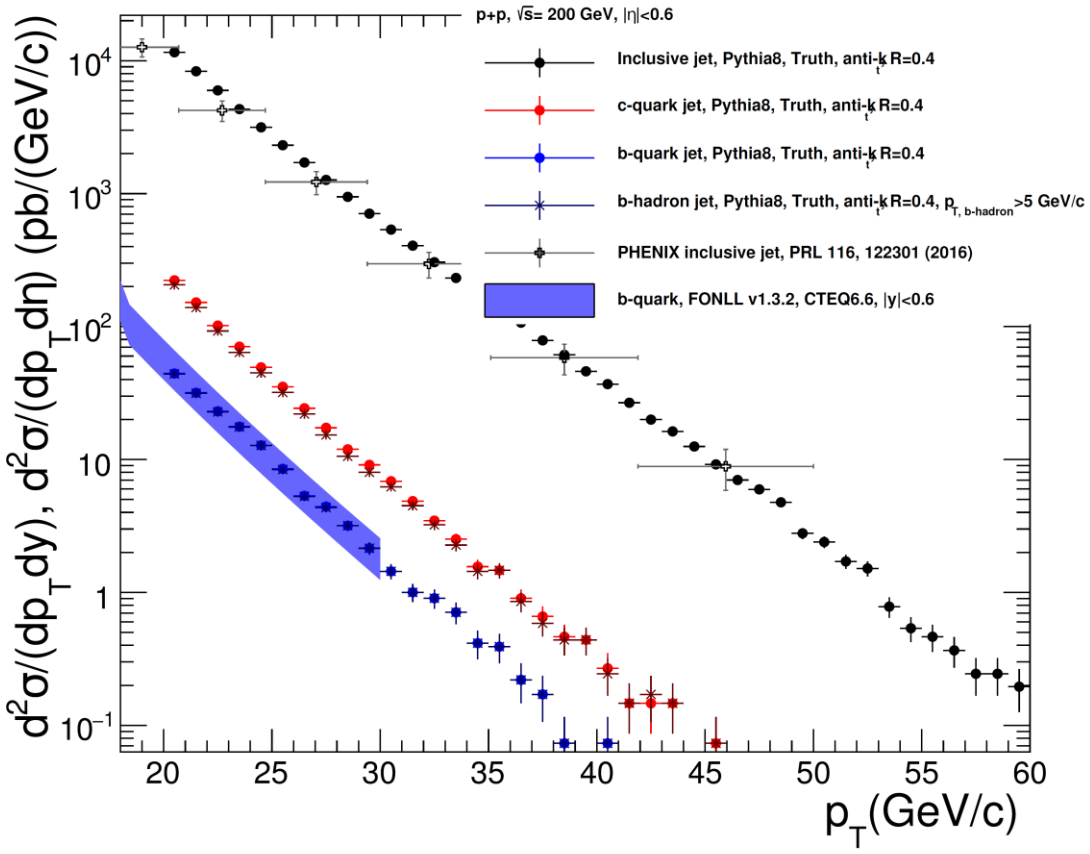




Lund String, Eur. Phys. J. C 17, 137–161 (2000)

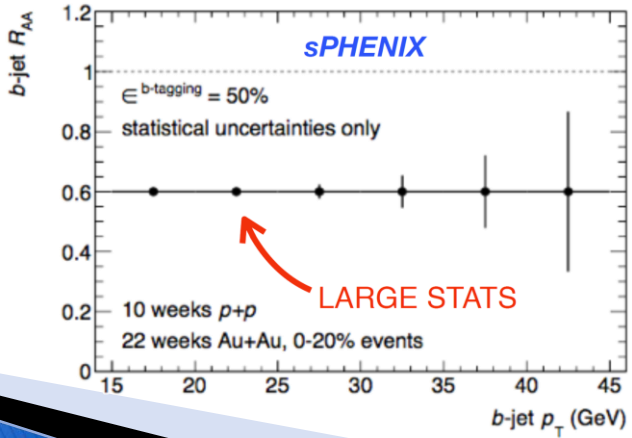


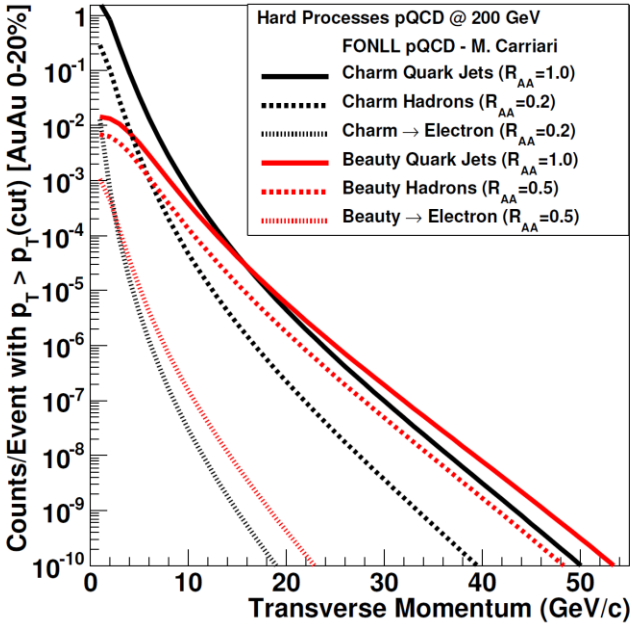
Cross section from pythia8



B-jet tagging – Decay lepton tagging

- None-photonic lepton has been a successful tool in studying heavy quark behavior in QGP
- Given a jet detected, lepton tagging in or near the jet cone could enhance HF jet fraction due to larger fraction of B(->d)->e decay than h->e decays.
  - Benefit:
    - Not necessarily require a DCA capability. No additional sPHENIX detector required
    - (Largely) orthogonal to and cross check life-time-based B tagging: e.g. DCA-track-counting and Secondary vertex mass methods
  - Cost: B->e branching ratio (~20%), electron identification efficiency, (b-tagging efficiency)
- Challenge:
  - Exploring possibility @ RHIC energy
  - Signal/background ratio and
  - Optimization both in $j_{T,e}$ and DCA_e
  - Statistics

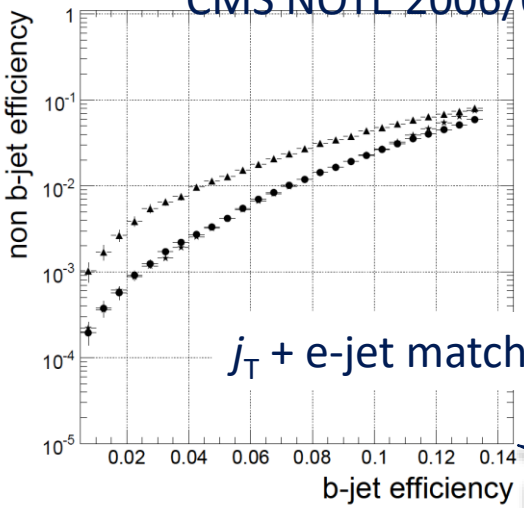




Decay lepton tagging - CMS studies (muon tagging)

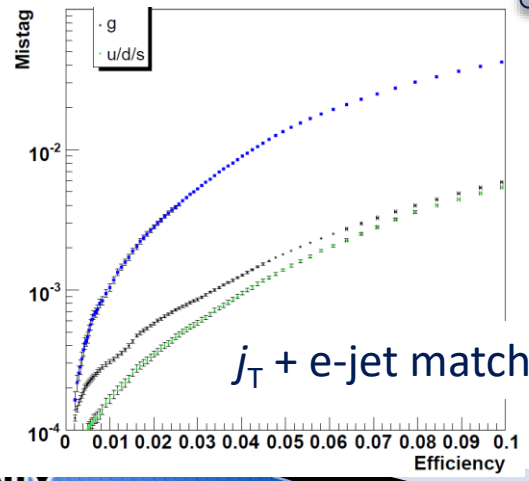
Rejection VS tagging eff.

CMS NOTE 2006/043



j_T + e-jet matching + DCA_e

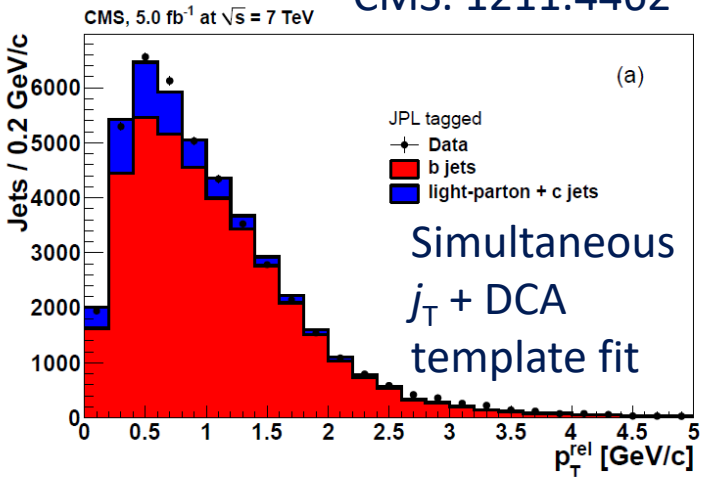
Suffer of B->μ BR



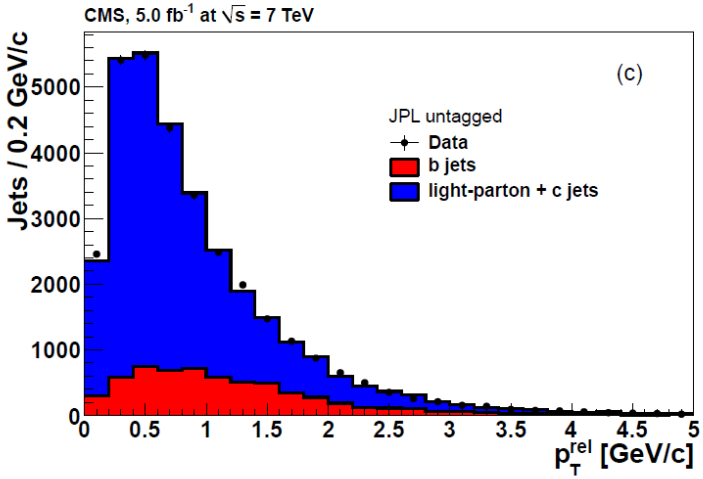
j_T + e-jet matching ~~no DCA_e~~

As cross check to JP/L method

CMS. 1211.4462

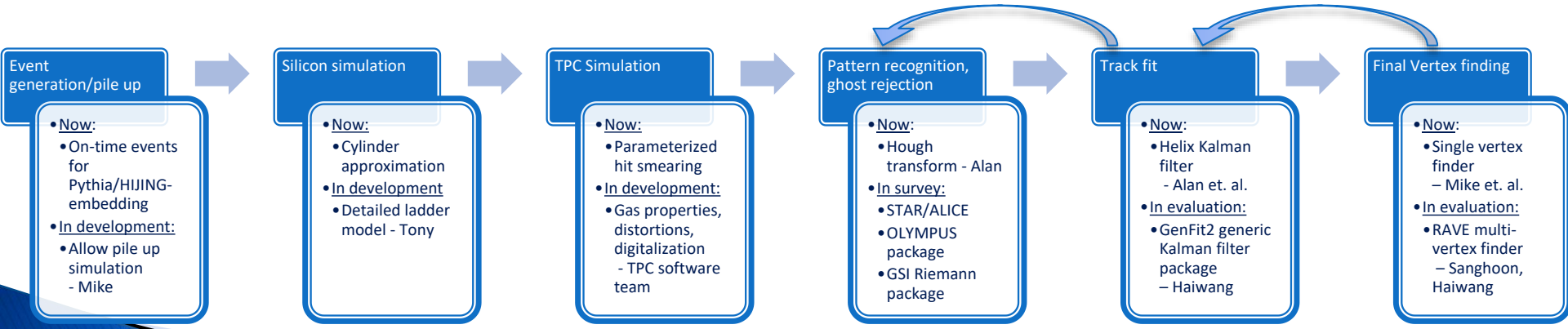


Simultaneous j_T + DCA template fit



sPHENIX tracking simulation and reconstruction chain

- A chain of full detector Geant4 simulation and reconstruction software developed for sPHENIX, used in current detector and physics performance projection
- Limitations in current software that need to be evolved for the next stage
- Many new developments hold back before the Sept-tracking review. Now to be coordinated to be made default.



https://indico.bnl.gov/conferenceDisplay.py?confId=1930